Extremely High Energy Neutrinos

A. Ringwald

http://www.desy.de/˜ringwald

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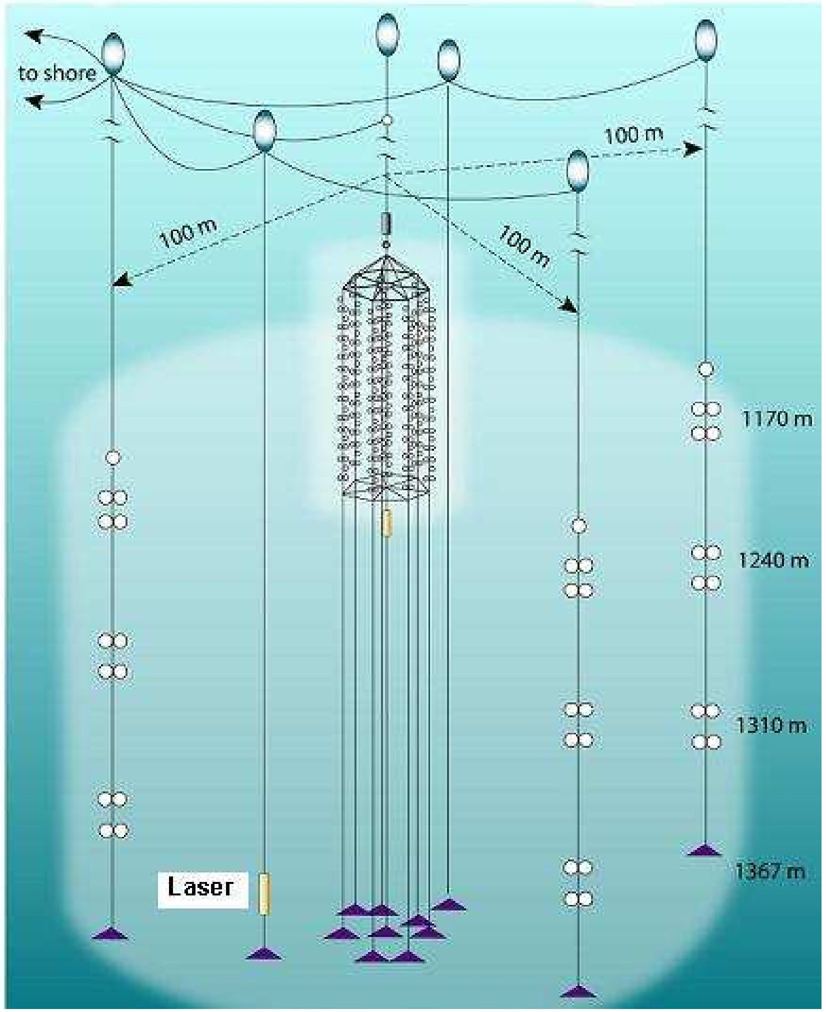
February 3, 2006, Vrije Universiteit, Amsterdam, Netherlands

1. Introduction

- Existing observatories for (**E**xtreme-ly) **H**igh **E**nergy **C**osmic ν's

BAIKAL Neutrino Telescope:



[baikalweb.jinr.ru/]

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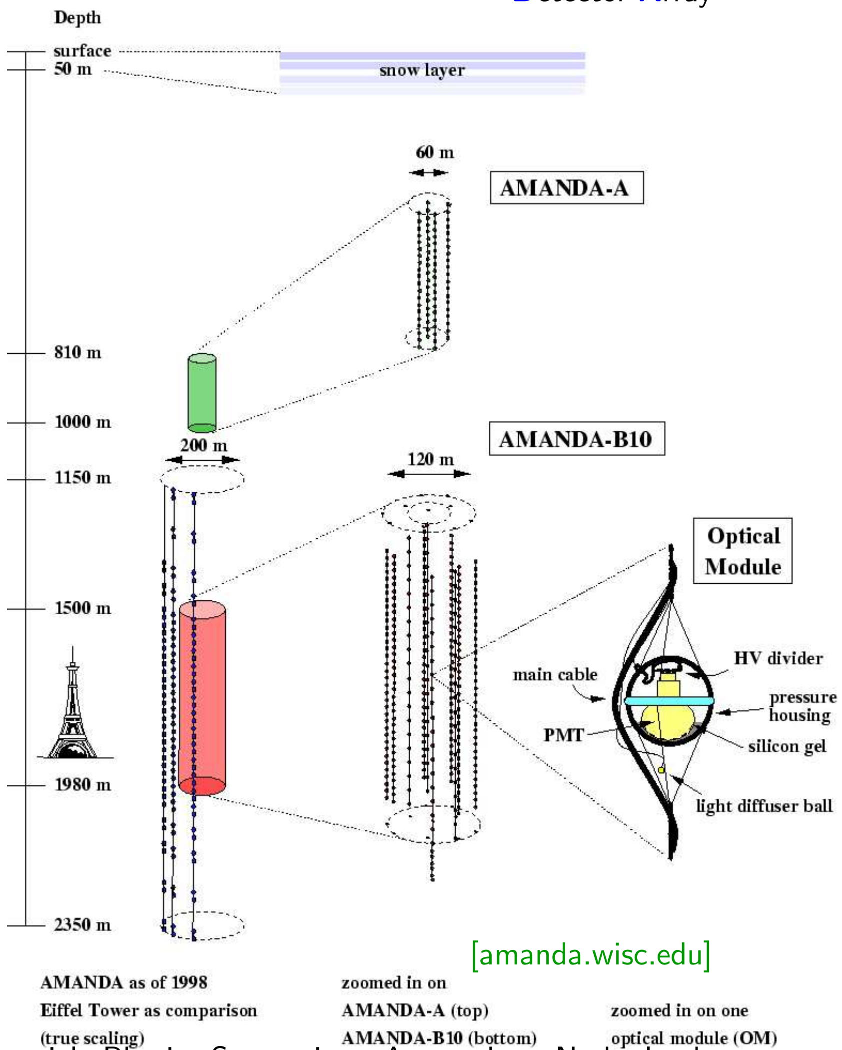
AMANDA: **A**ntarctic **M**uon **A**nd **N**eutrino **D**etector **A**rray



[amanda.wisc.edu]

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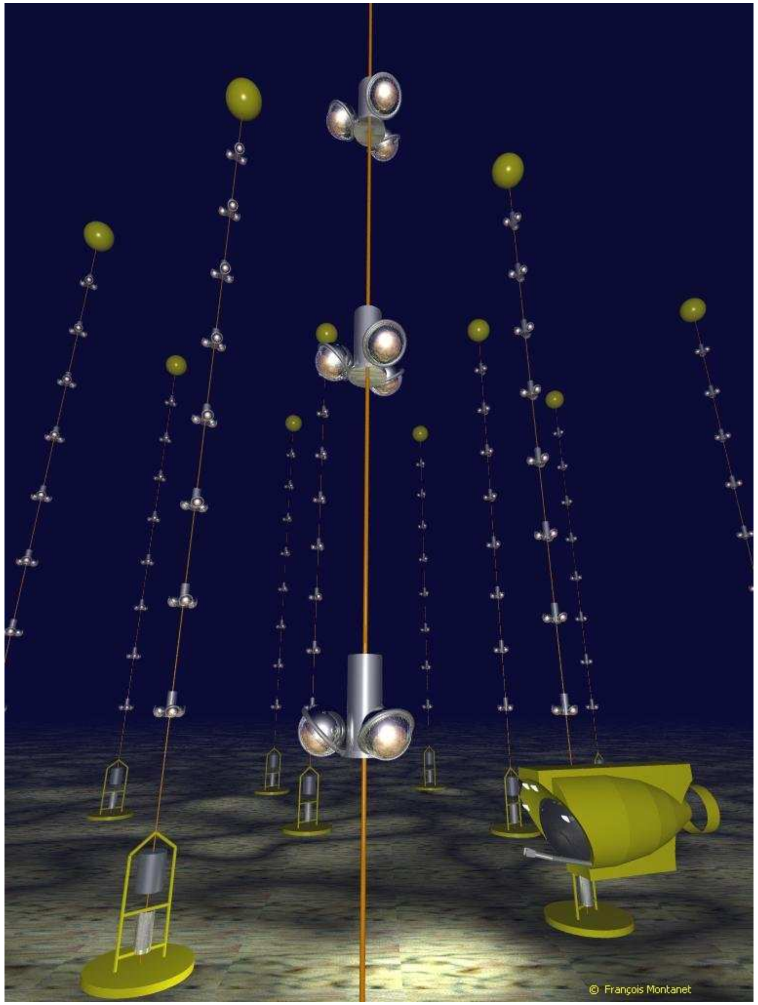
ANTARES: **A**stronomy with a **N**eutrino **T**elescope and **A**byss environmental **RES**earch



[antares.in2p3.fr/index.html]

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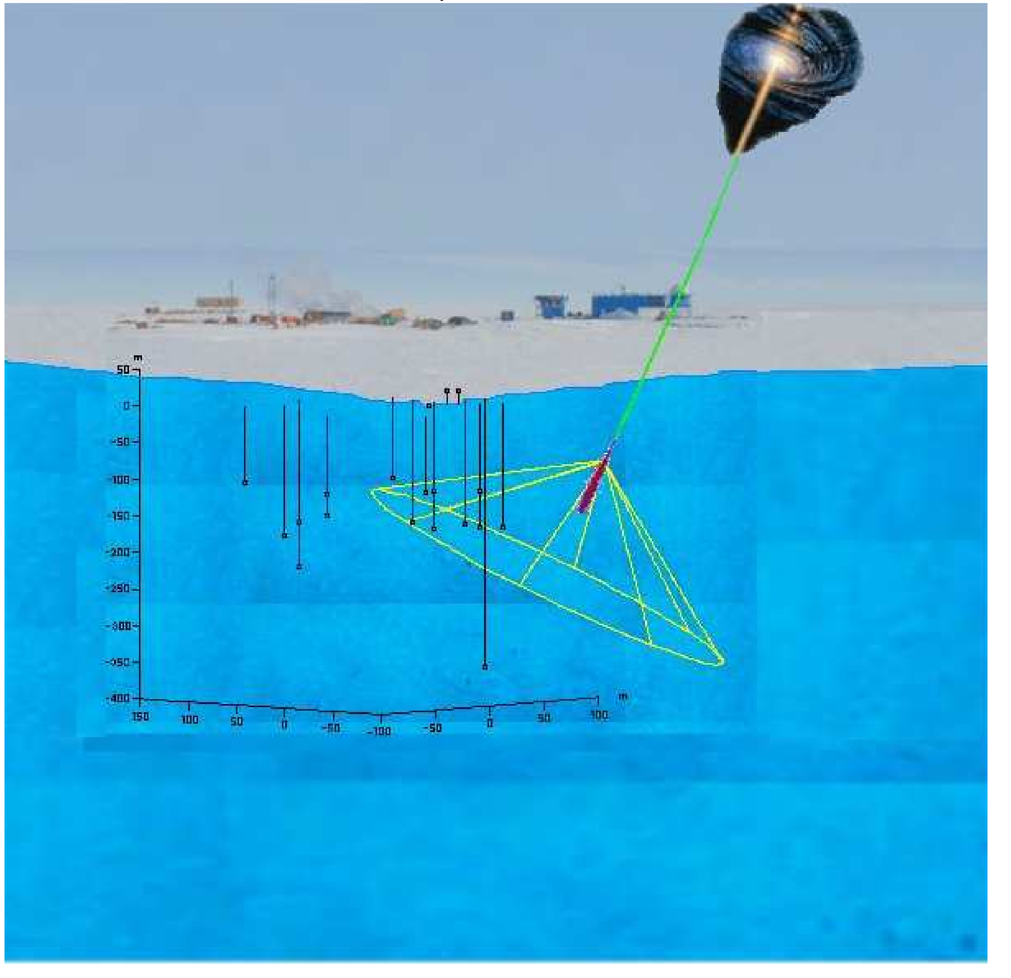
RICE: Radio **I**ce **C**erenkov **E**xperiment



[www2.phys.canterbury.ac.nz/rice]

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GLUE: **G**oldstone **L**unar **U**ltra-high energy neutrino **E**xperiment

[http://www.physics.ucla.edu/ moonemp/public/]

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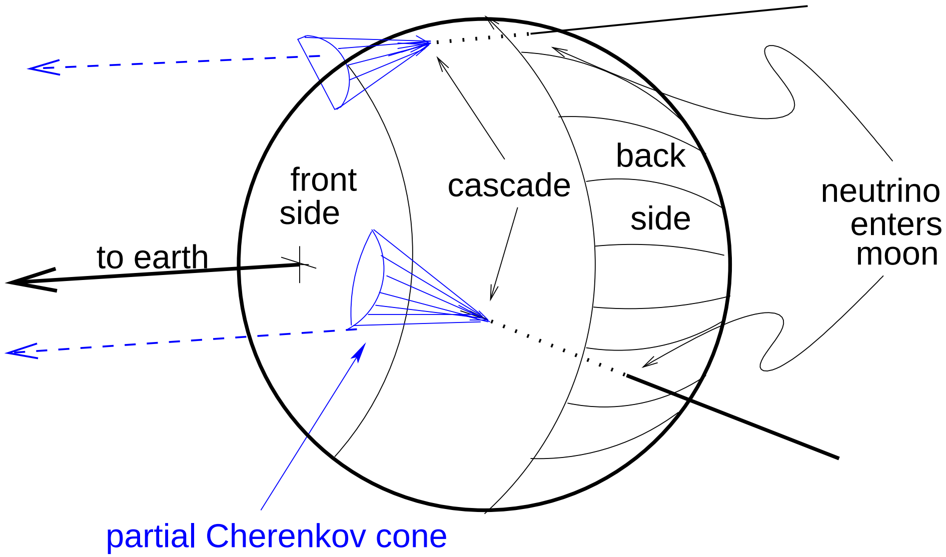

[Gorham *et al.* '04]

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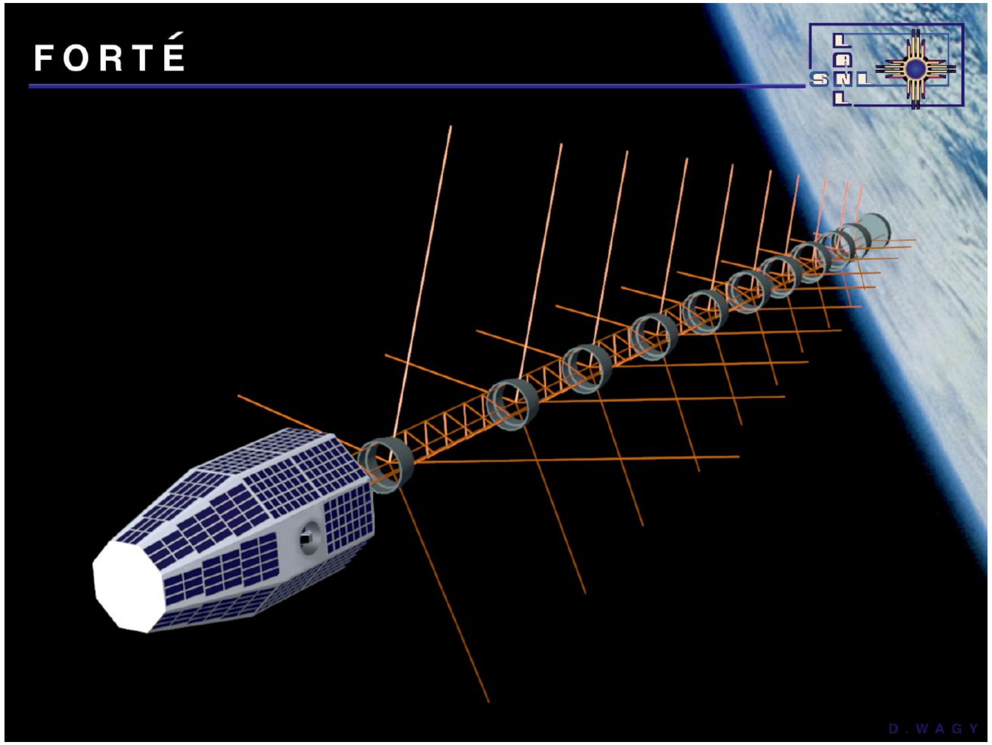
FORTE: **F**ast **O**n-orbit **R**ecording of **T**ransient **E**vents



[nis-www.lanl.gov/nis-projects/forte/]

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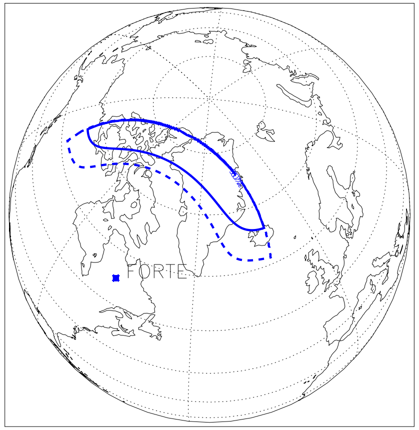

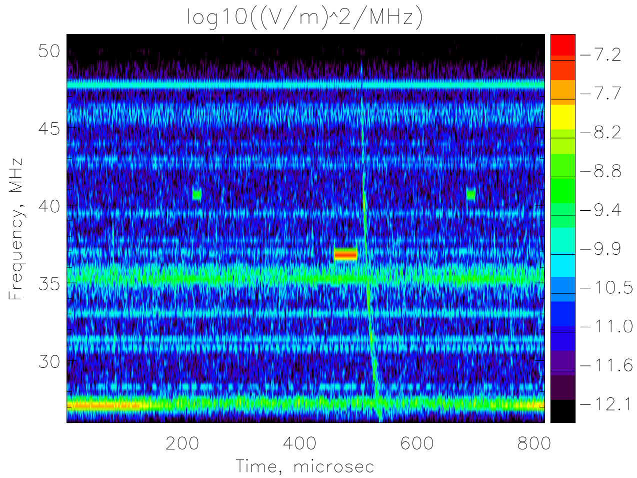

[Lehtinen *et al.* '04]

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ANITA-LITE: Prototype of **AN**tarctic **I**mpulsive **T**ransient **A**ntenna

[www.phys.hawaii.edu/ anita/web/index.htm]

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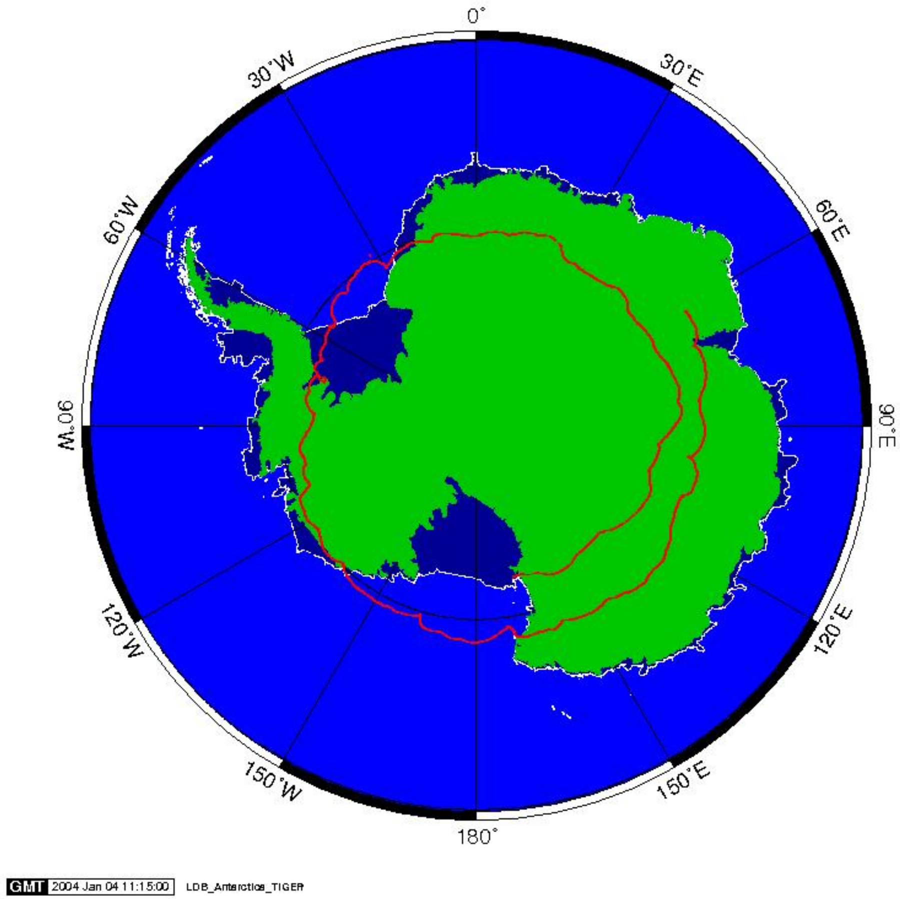

[cosray2.wustl.edu/tiger/index.html]

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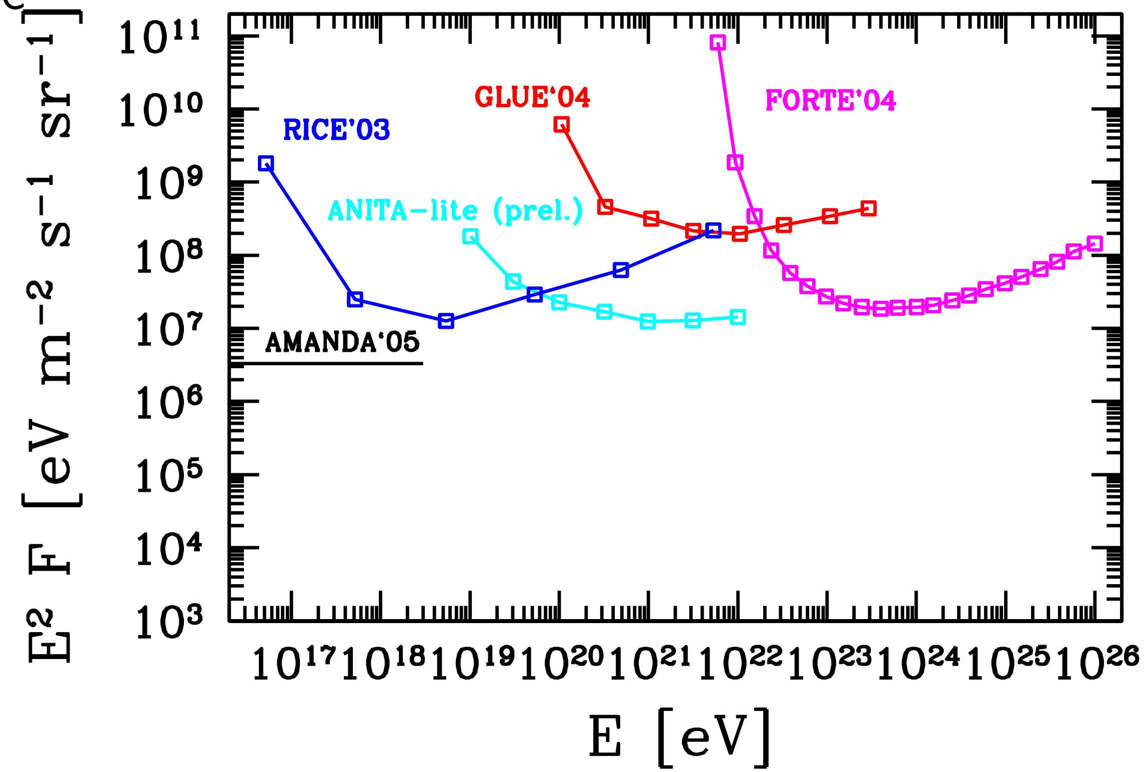

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- Existing observatories for (**E**xtremely) **H**igh **E**nergy **C**osmic ν's provide sensible upper bounds on flux
- Upcoming decade: progressively larger detectors for **EHECν's**

PAO: Pierre **A**uger **O**bservatory

[www.auger.org]

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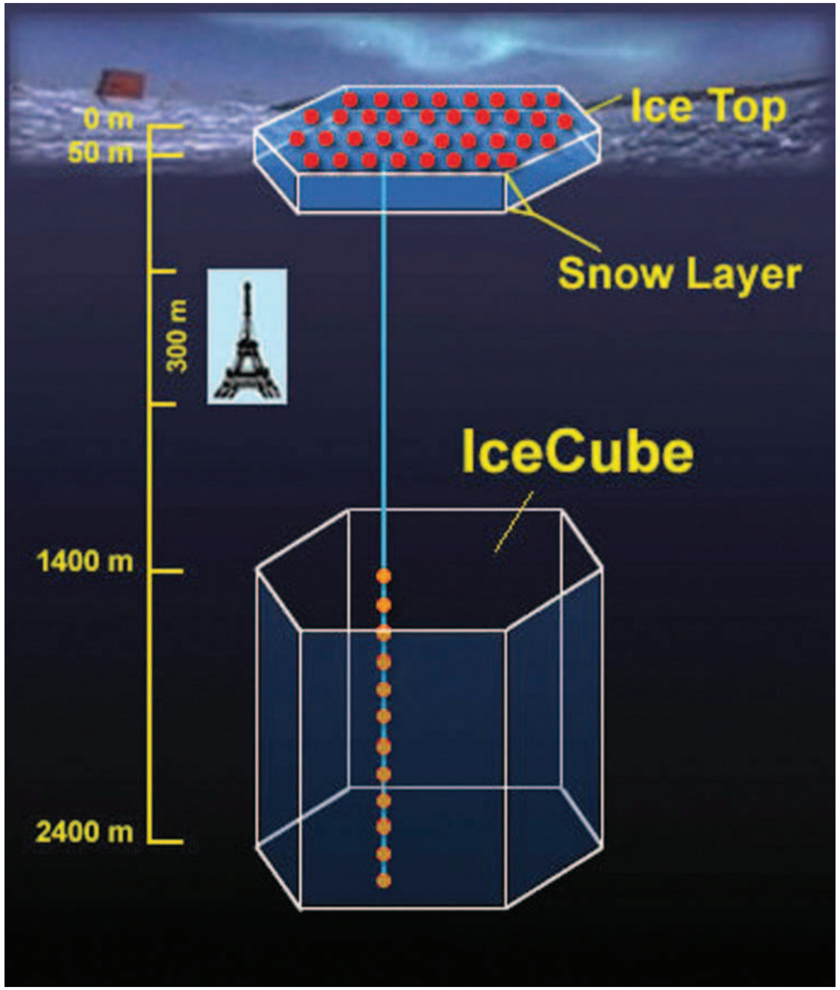
IceCube:



[icecube.wisc.edu]

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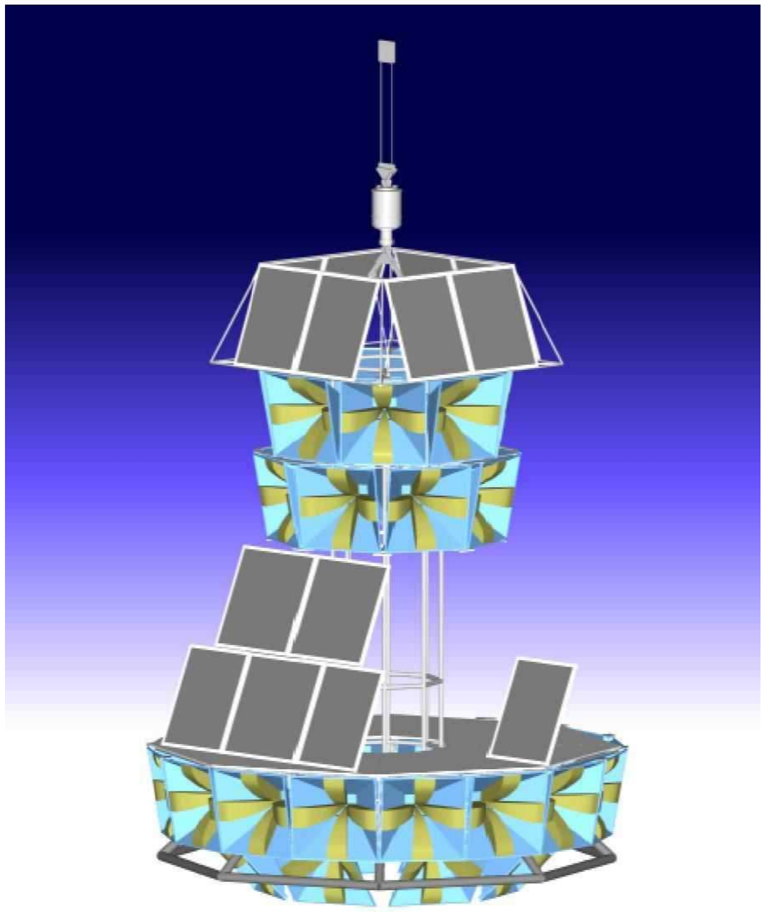

[www.ps.uci.edu/ anita/]

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WSRT: WeSterbork Radio Telescope

[Bacelar, ARENA Workshop '05]

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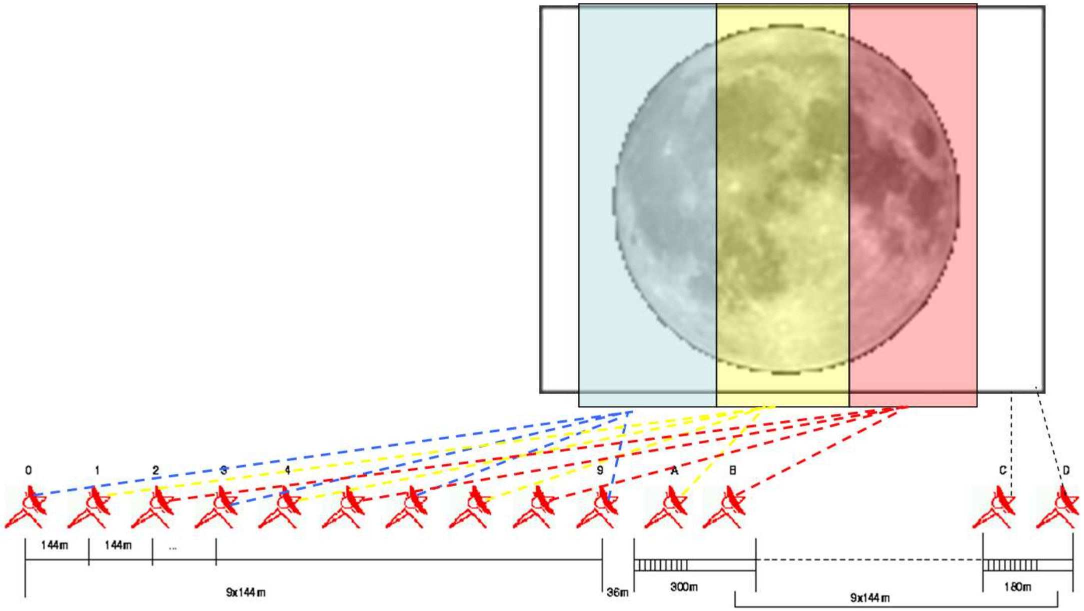

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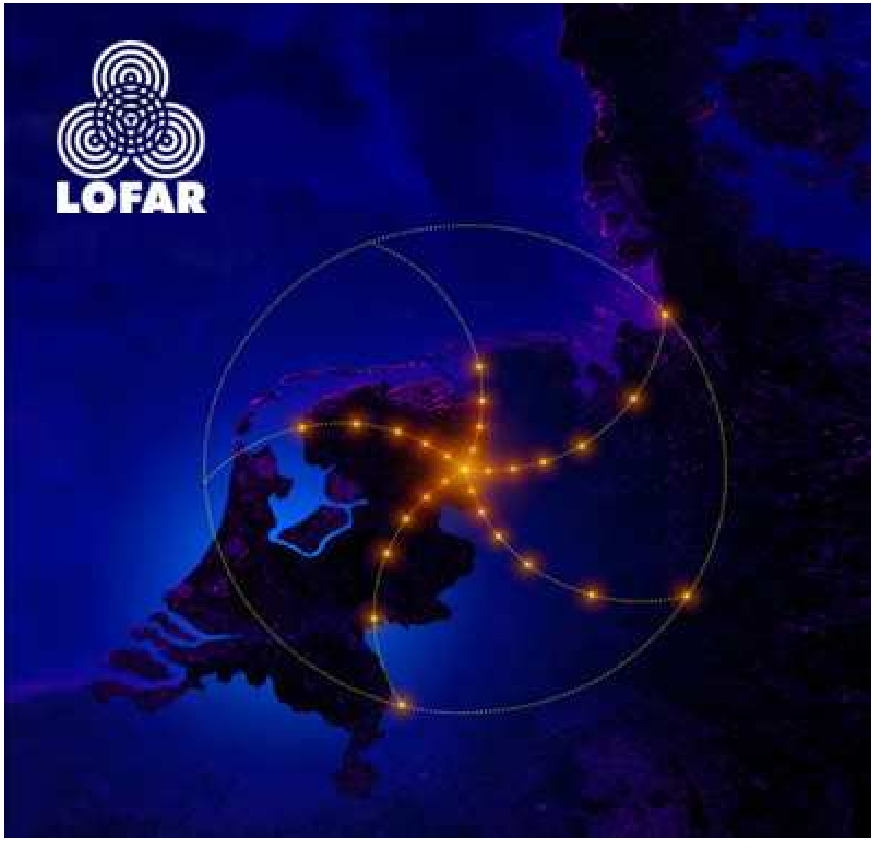
LOFAR:



[www.lofar.org]

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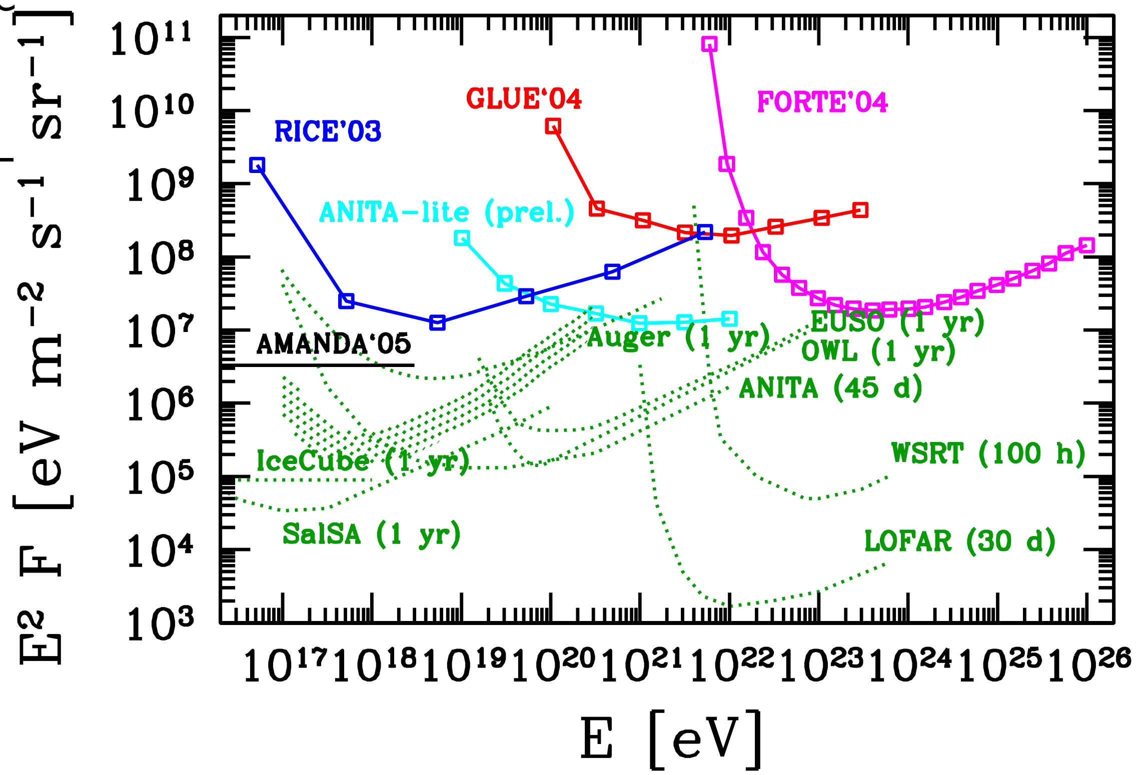

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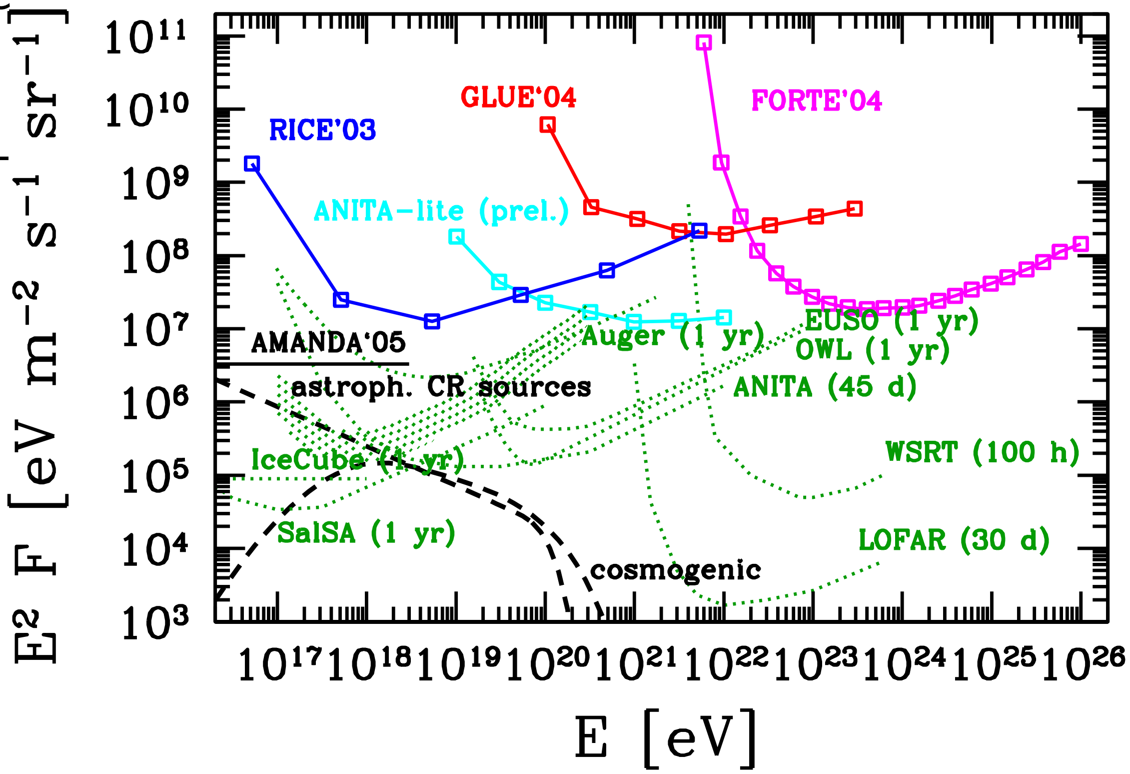
$\Rightarrow$ $E \geq 10^{16}$ eV:

$\rightarrow$ **Astrophysics** of cosmic rays

$\Rightarrow$ $E \geq 10^{17}$ eV:

$\rightarrow$ **Particle physics** beyond **LHC**



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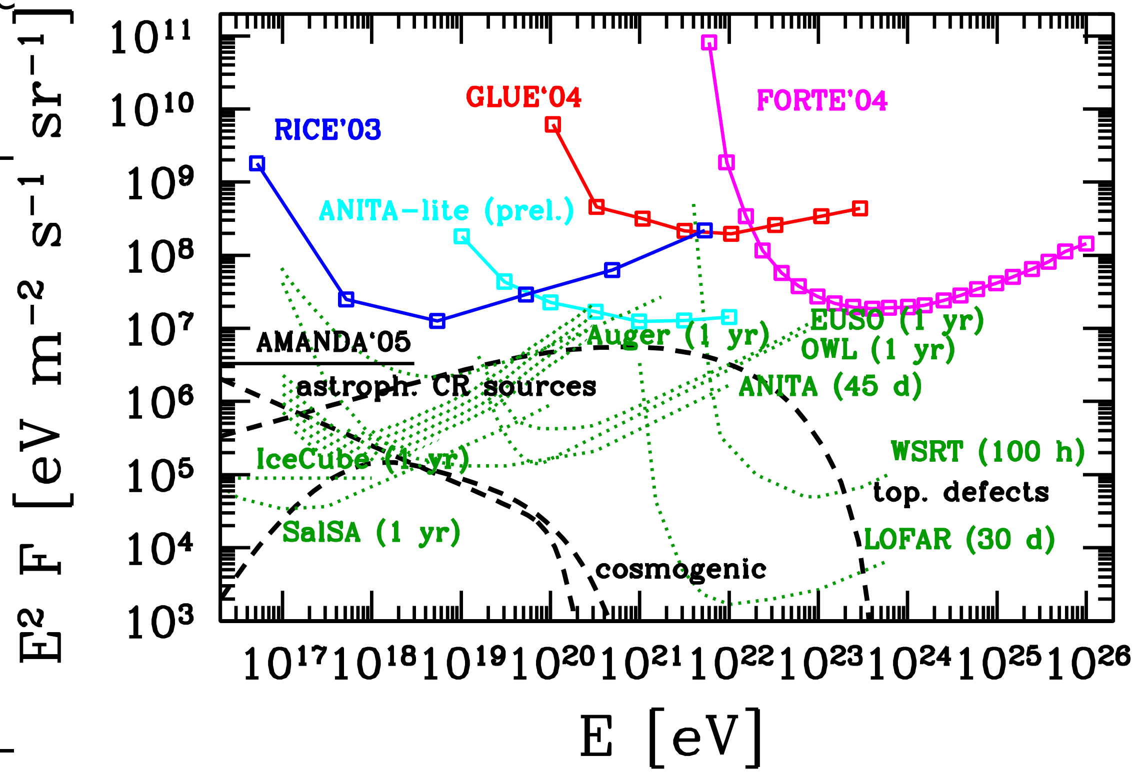
$\Rightarrow$ $E \geq 10^{21}$ eV:

$\longrightarrow$ **Cosmology:** relics of phase transitions; absorption on big bang relic neutrinos

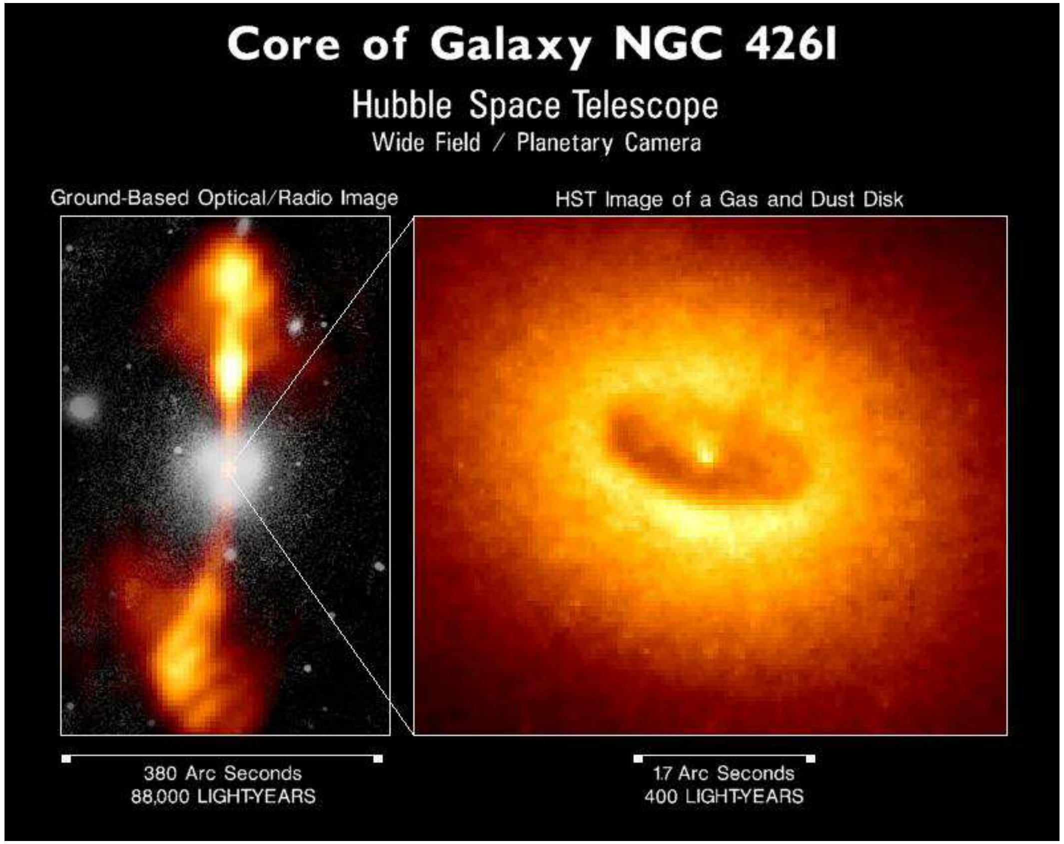


- **Further content:**

  2. **Sources and fluxes of EHEC neutrinos**
  3. **Fun with EHEC neutrinos**
  4. **Conclusions**

2. Sources and fluxes of EHEC neutrinos

- Paradigm for **astrophysical** extra-galactic source of protons and neutrinos: **shock acceleration**



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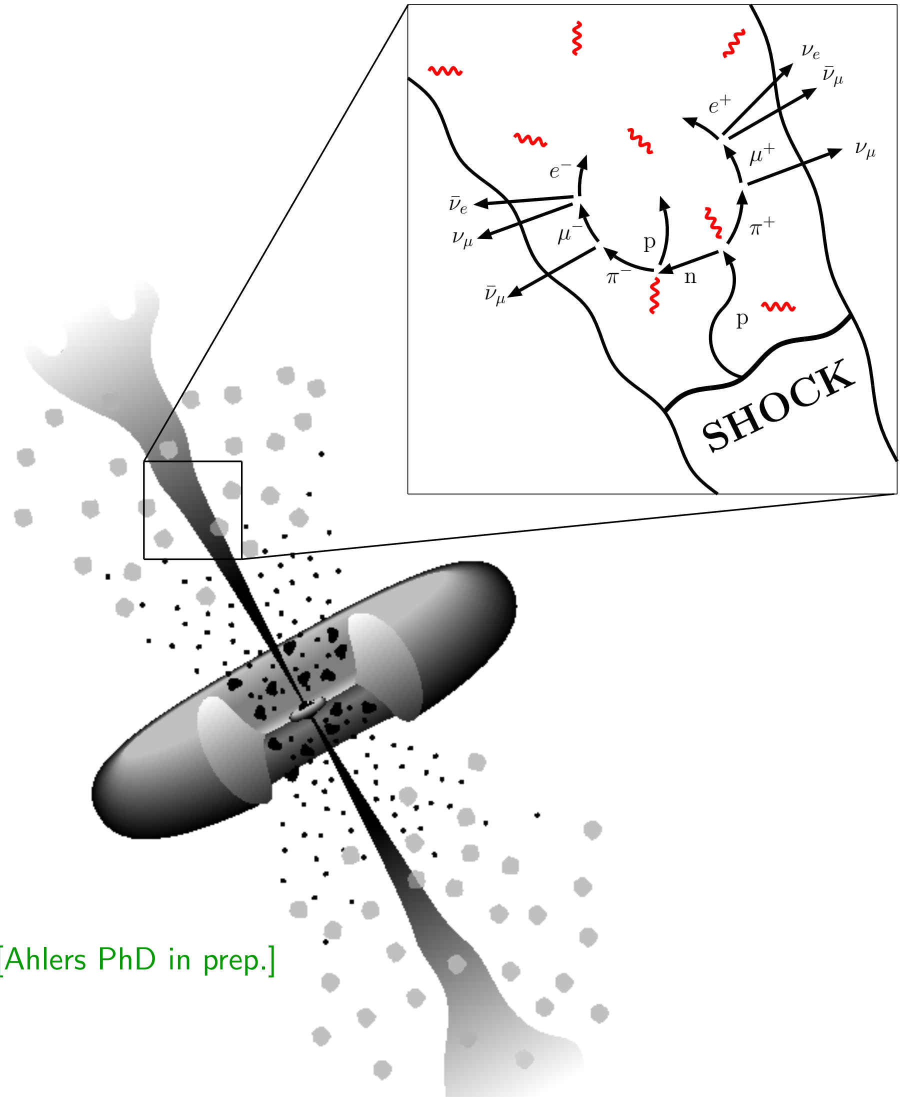
- Paradigm for **astrophysical** extra-galactic source of protons and neutrinos: **shock acceleration**
  - p's, confined by magnetic fields, accelerate through repeated scattering by plasma shock fronts
  - production of π's and n's through collisions of the trapped p's with ambient plasma produces γ's, ν's



[Ahlers PhD in prep.]

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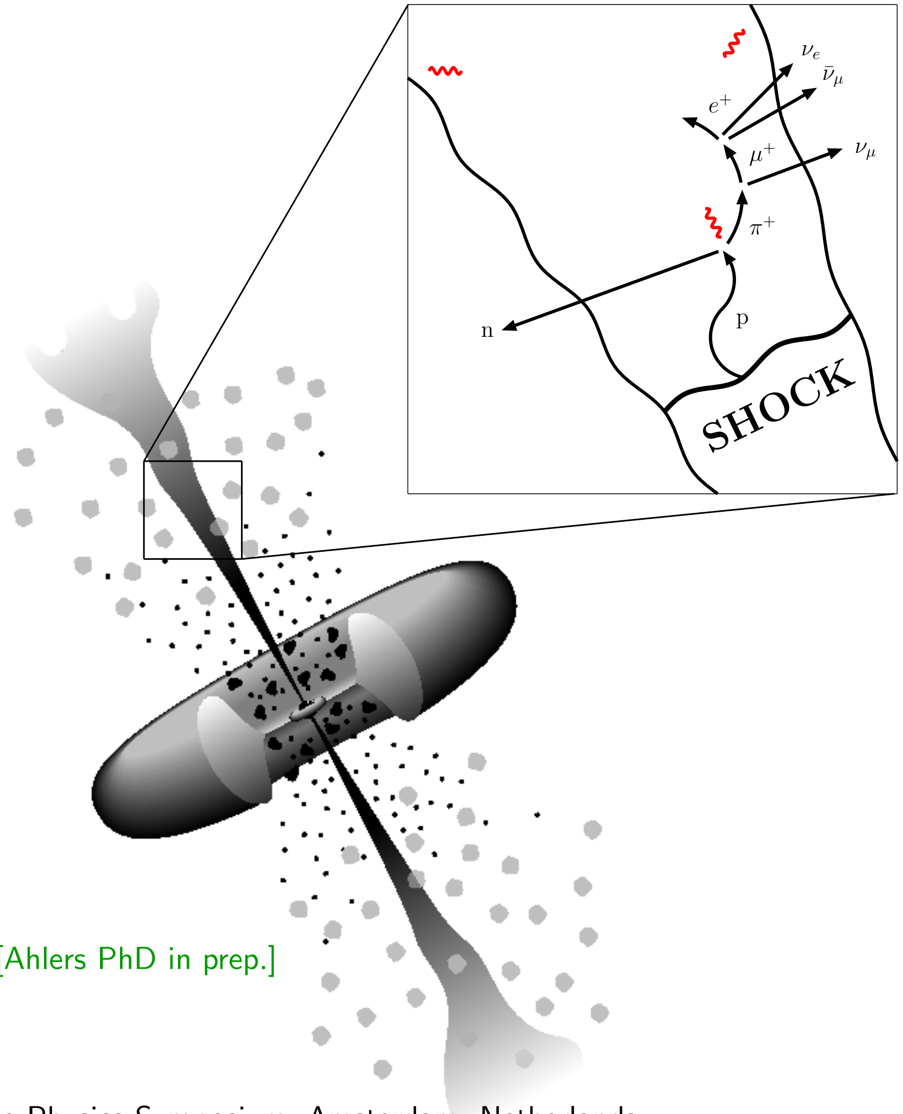

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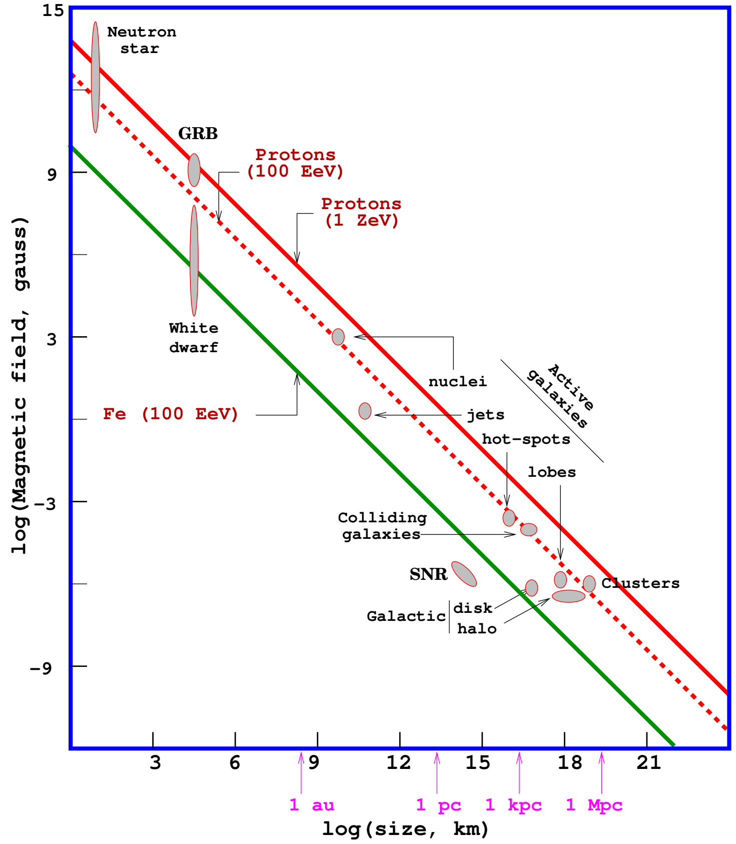
Hillas: $E_p \lesssim 10^{21}$ eV

Hillas-plot
(candidate sites for E=100 EeV and E=1 ZeV)



E max ~ ZBL (Fermi)
E max ~ ZBL Γ (Ultra-relativistic shocks-GRB)

[Pierre Auger Observatory]

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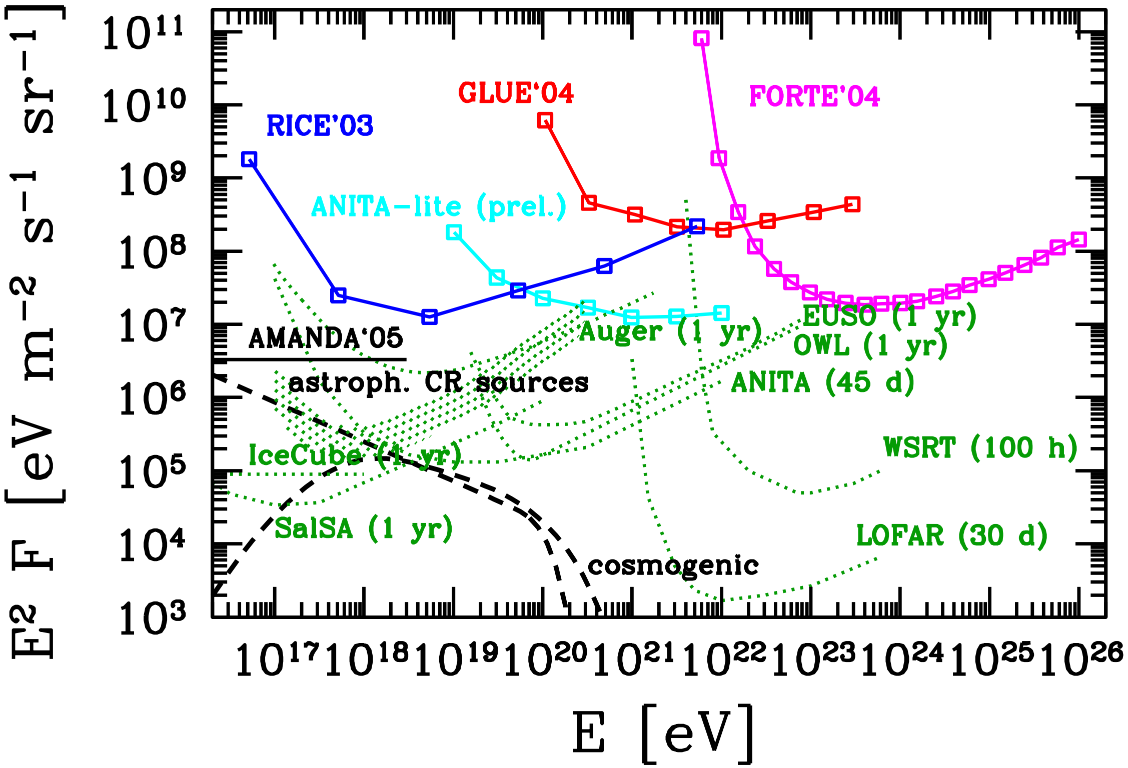

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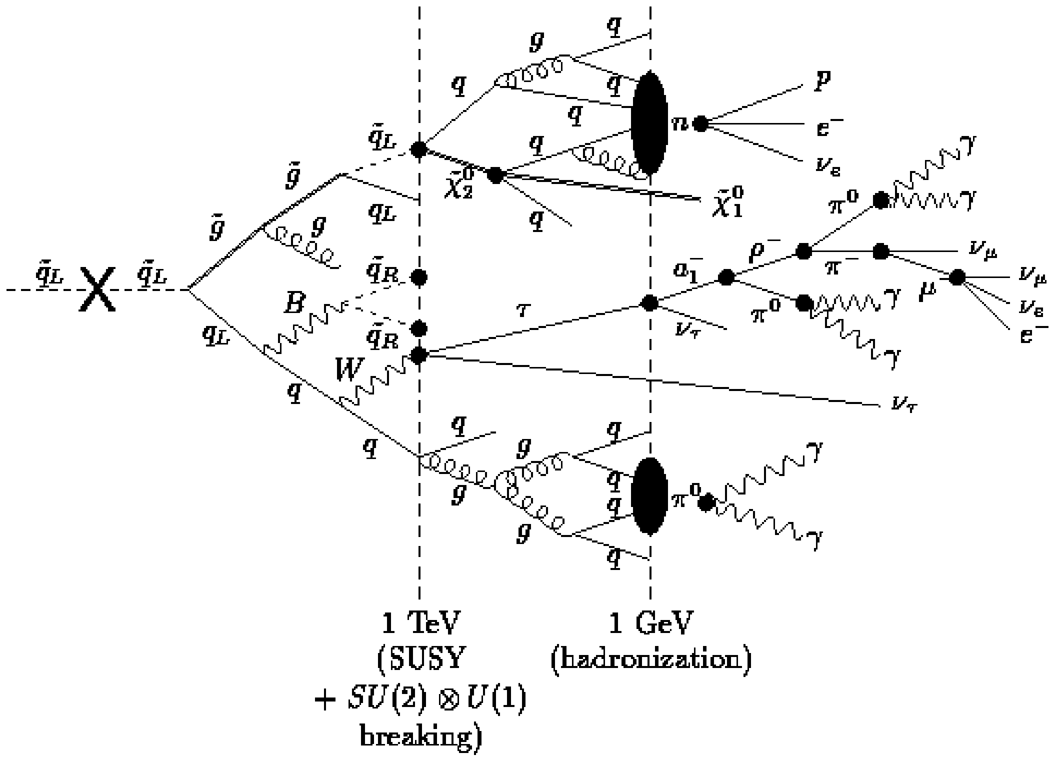
$\Rightarrow$ EHEC ($E_\nu \gtrsim 10^{20}$ eV) neutrinos

- $\leftarrow$ yet unknown acceleration sites
- $\leftarrow$ other acceleration mechanism
- $\leftarrow$ **decay of superheavy particles**



[Barbot,Drees '02]

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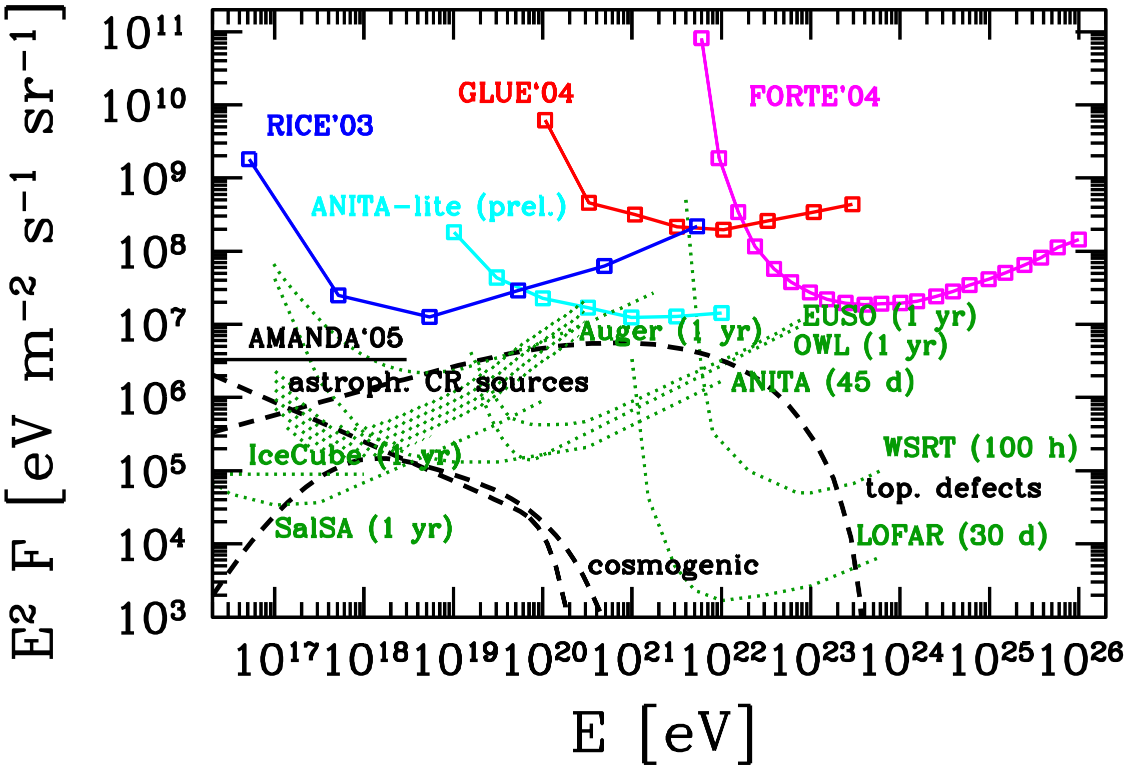
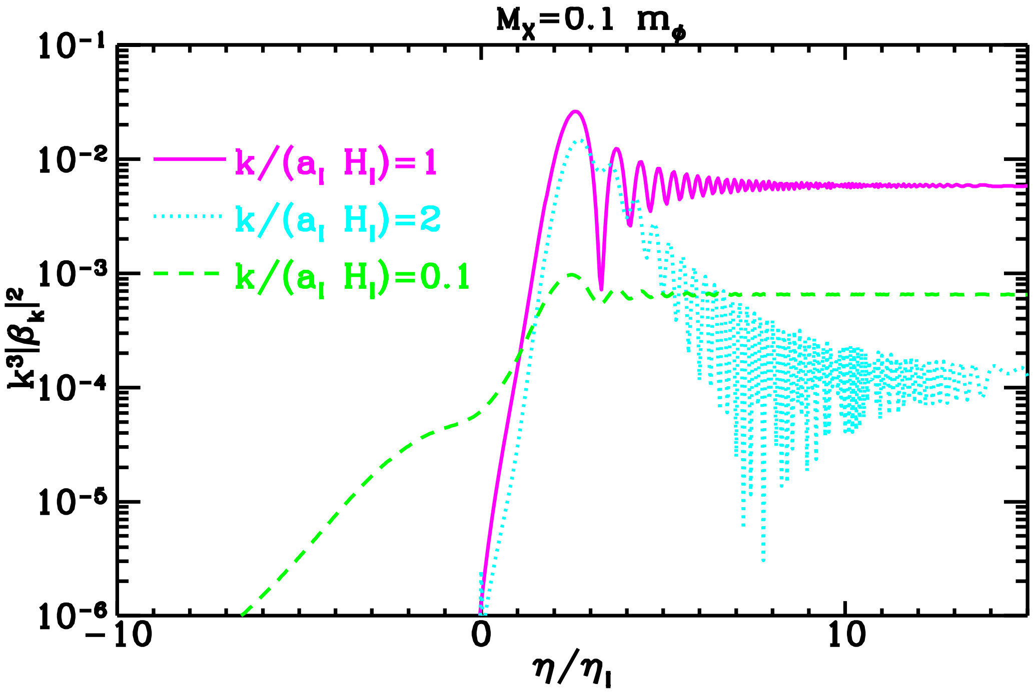


Top-down scenarios for EHEC neutrinos

- Existence of superheavy particles with $10^{12}\ \mathrm{GeV} \lesssim m_X \lesssim 10^{16}\ \mathrm{GeV}$, produced during and after inflation through e.g.
  - particle creation in time-varying gravitational field



[Kolb,Chung,Riotto '98]

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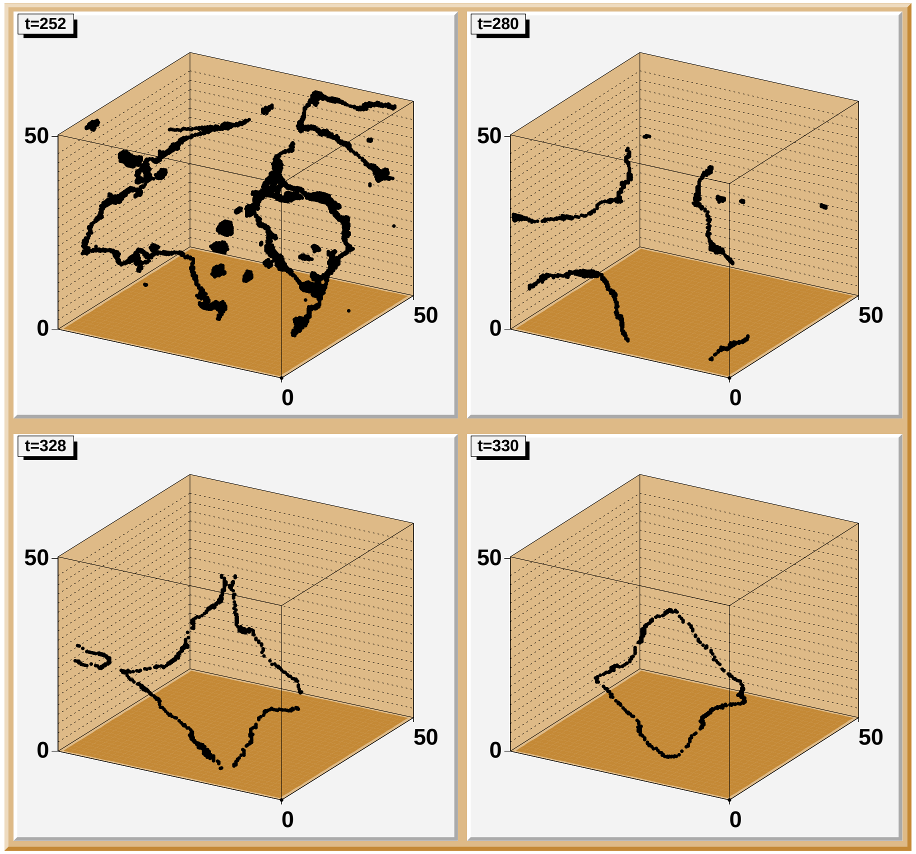
  - decomposition of topological defects, formed during preheating, into their constituents



[Tkachev,Khlebnikov,Kofman,Linde '98]

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  $\Rightarrow$ EHEC ν's from decay or annihilation of superheavy dark matter (for $\tau_X \gtrsim \tau_U$)
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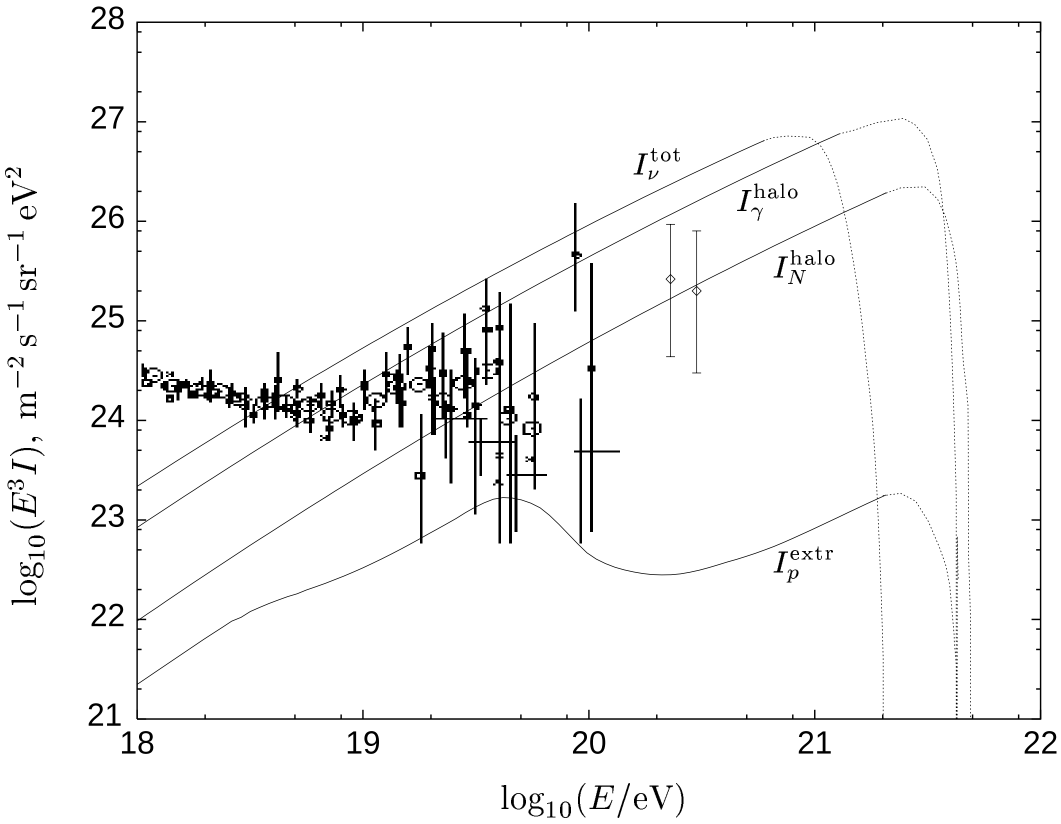

[Berezinsky,Kachelriess,Vilenkin '97]

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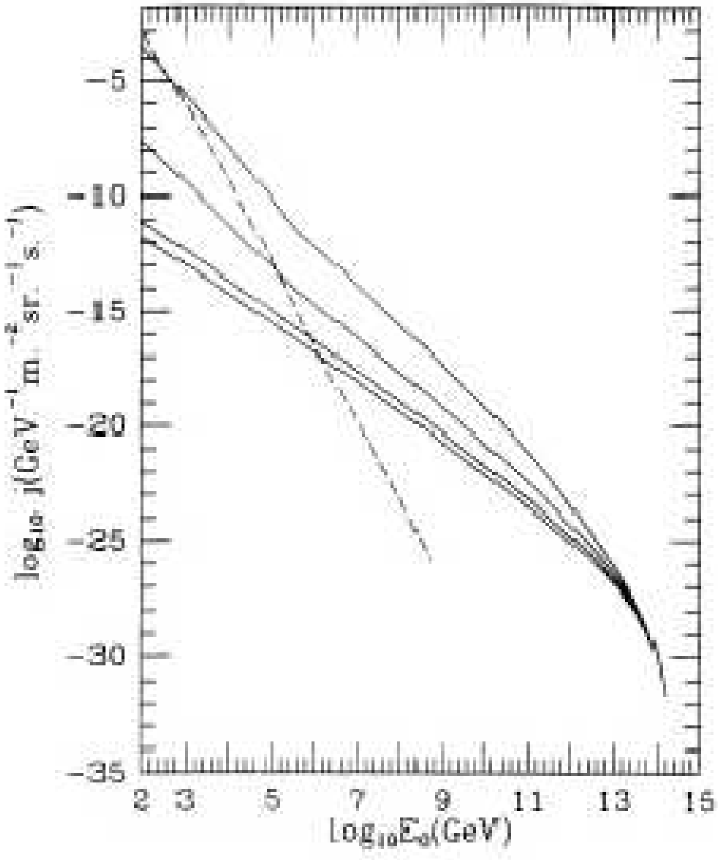
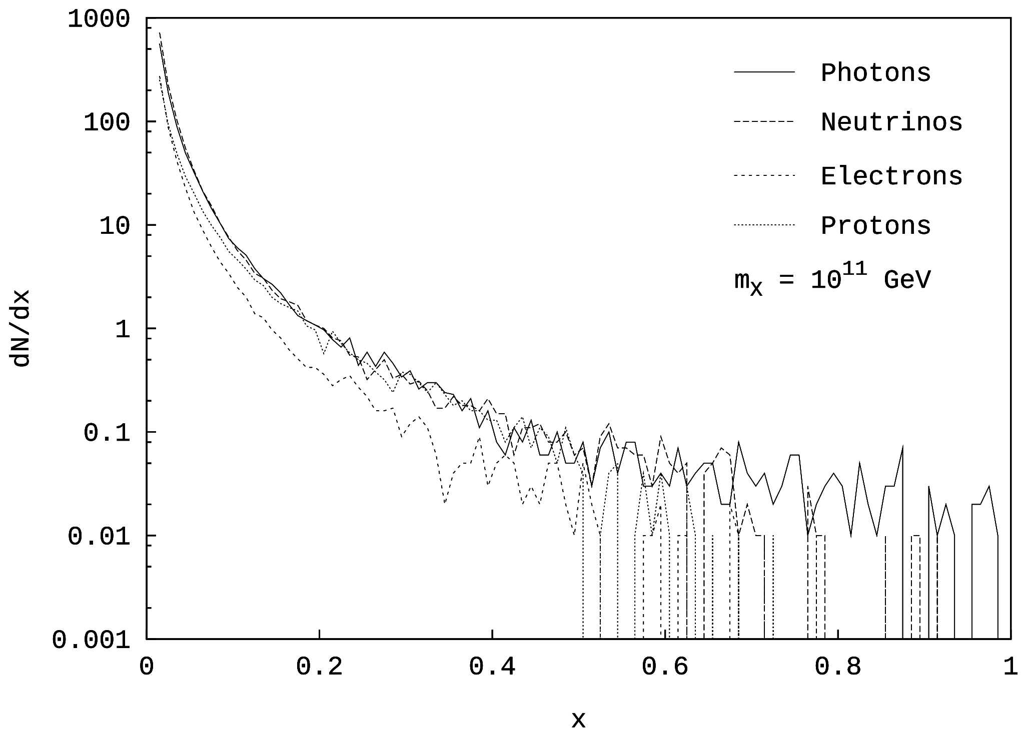
  $\Rightarrow$ EHEC ν's from topological defects



[Bhattacharjee,Hill,Schramm '92]

Top-down scenarios for EHEC neutrinos

- **Injection spectra:** fragmentation functions $D_i(x, \mu)$, $i = p, e, \gamma, \nu$, determined via
  – Monte Carlo generators



[Birkel,Sarkar '98]

Top-down scenarios for EHEC neutrinos

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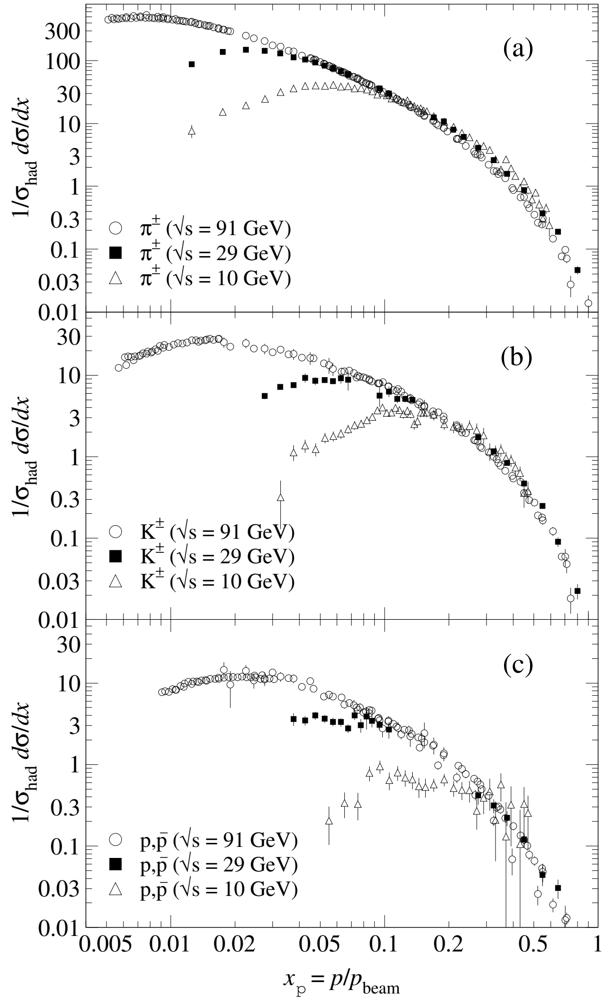
  - DGLAP evolution from experimental initial distributions at e.g. $\mu = m_Z$



[Particle Data Group '04]

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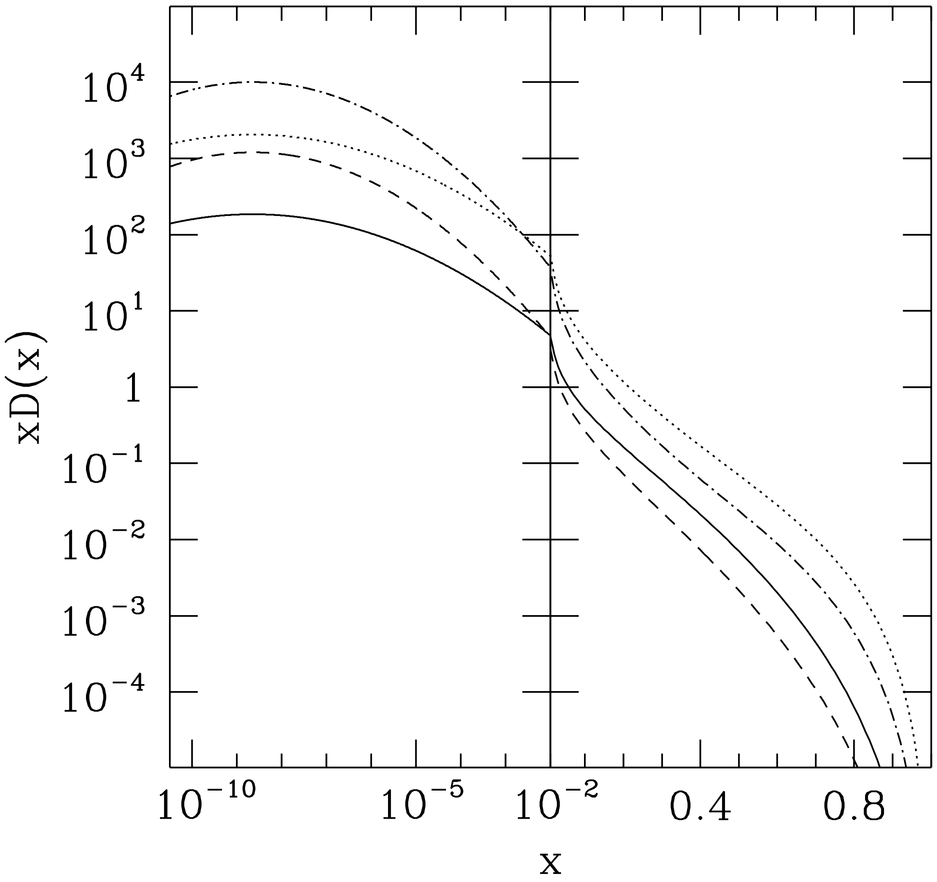

[Fodor,Katz '01]

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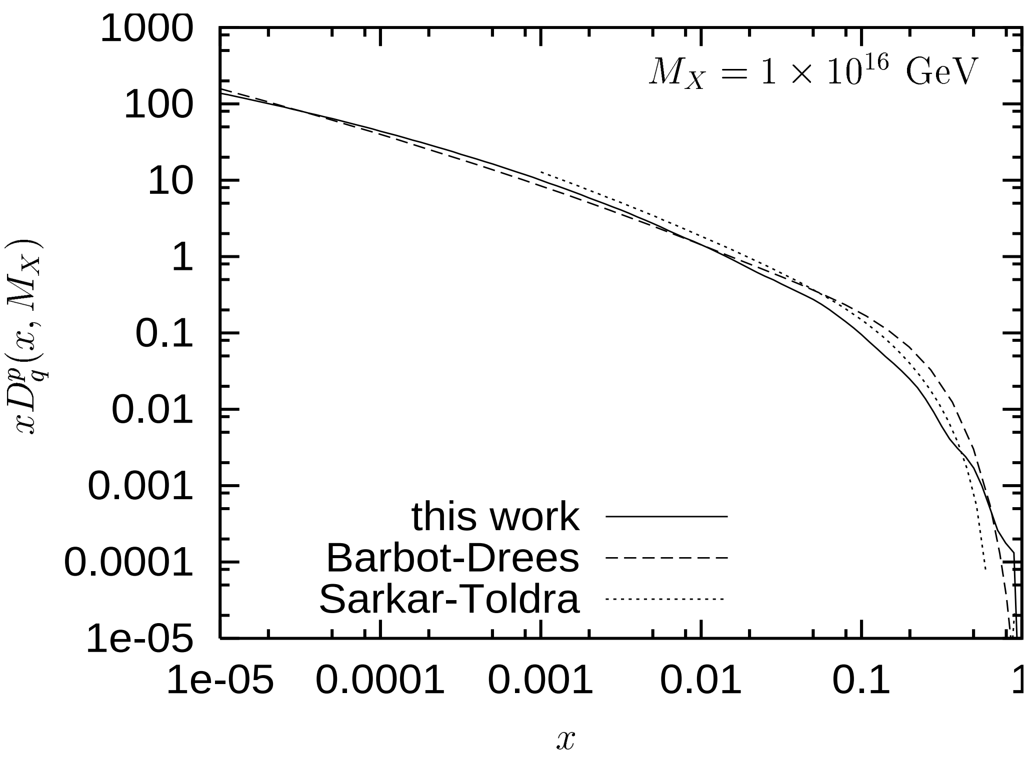

[Aloisio,Berezinsky,Kachelriess ‘04]

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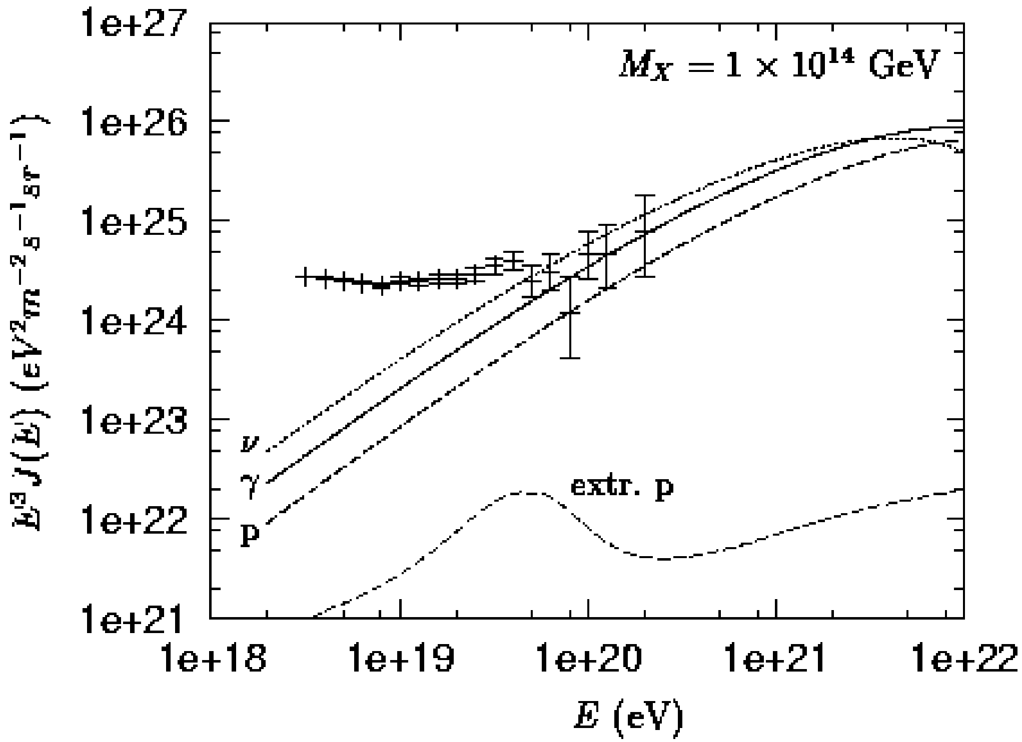
  - for superheavy dark matter, injection nearby: $j_\nu \sim j_\gamma \sim j_p$



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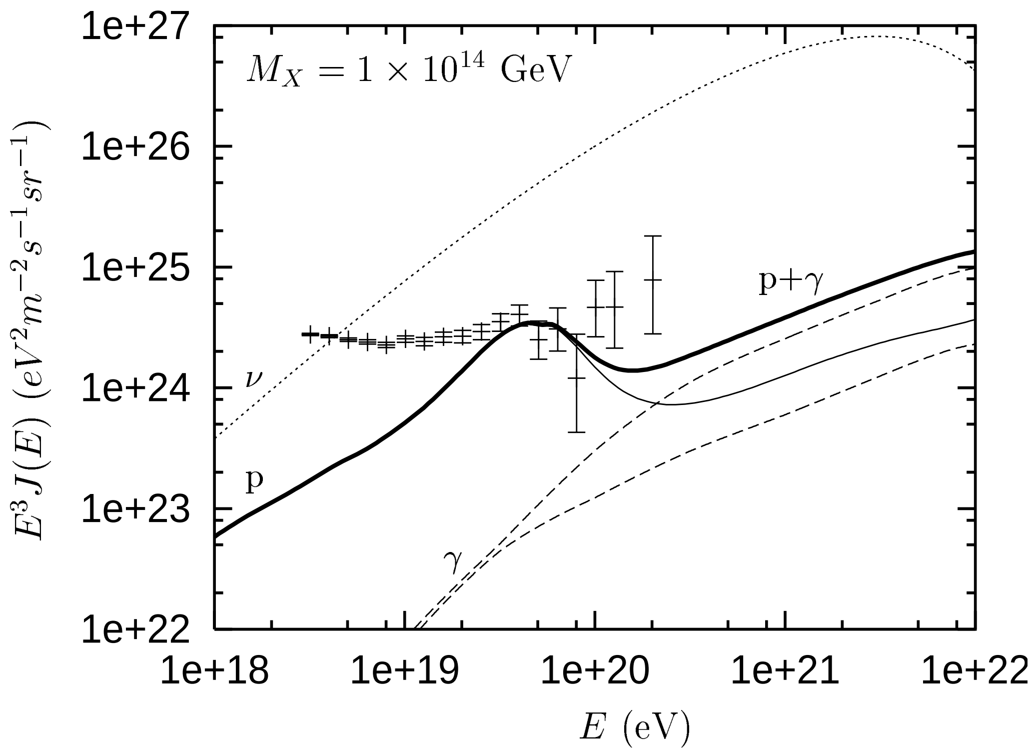
- **Spectra at Earth:**
  - for superheavy dark matter, injection nearby: $j_\nu \sim j_\gamma \sim j_p$
  - for topological defects, injection far away: $j_\nu \gg j_\gamma \sim j_p$



[Aloisio,Berezinsky,Kachelriess '04]

Top-down scenarios for EHEC neutrinos

- **How natural?**
  - **Superheavy dark matter:** need symmetry to prevent fast X decay
    - $*$ gauge $\Rightarrow$ X stable
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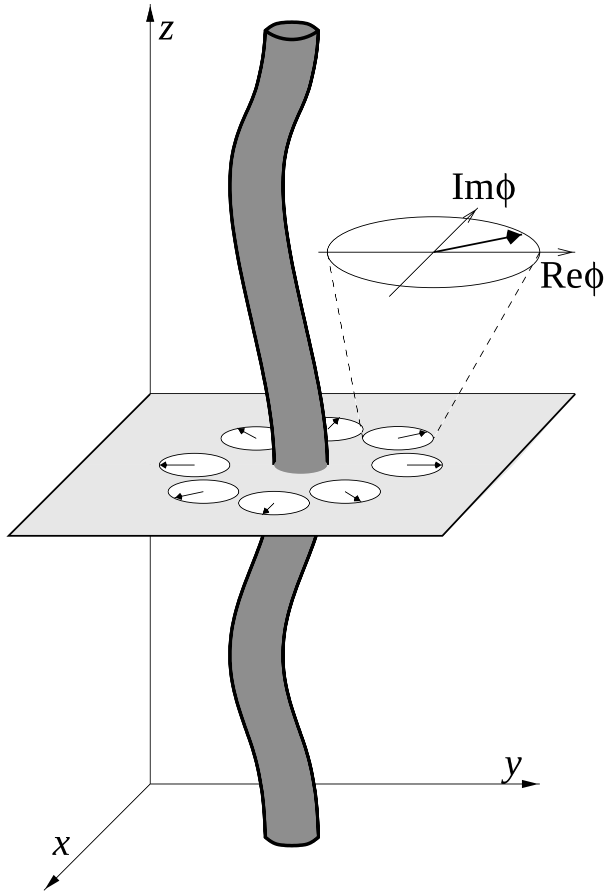
    - $*$ $\mathrm{G} \to \mathrm{H} \times \mathrm{U}(1)$ SB: monopoles
    - $*$ $\mathrm{U}(1)$ SB: ordinary or superconducting strings



[Rajantie '03]

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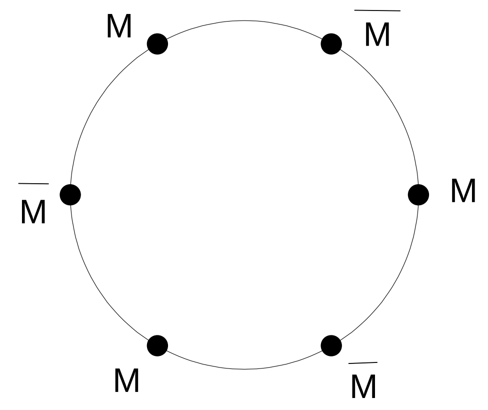
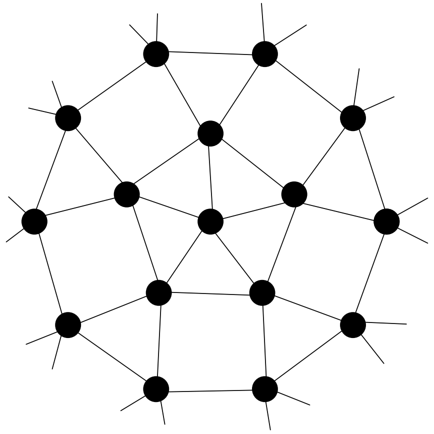
    - $*$ $\mathrm{U}(1)$ SB: ordinary or superconducting strings
    - $*$ $\mathrm{G} \to \mathrm{H} \times \mathrm{U}(1) \to \mathrm{H} \times \mathrm{Z}_N$ SB: monopoles connected by strings

NECKLACE



MS NETWORK

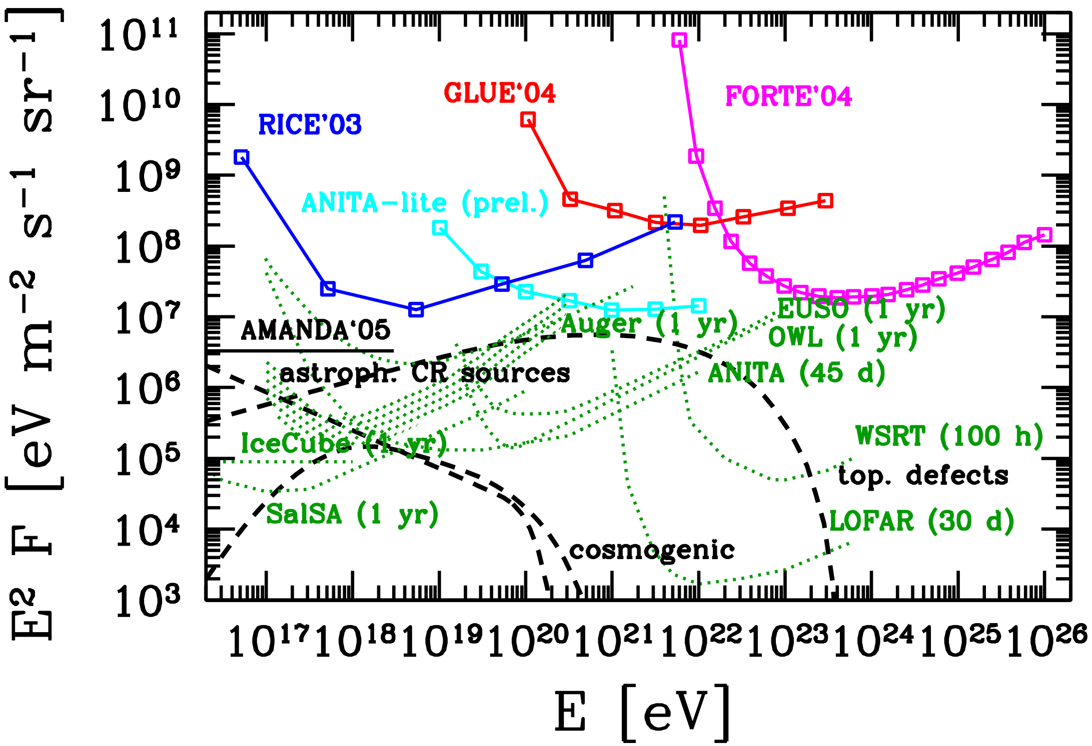


[Berezinsky '05]

3. Fun with EHEC neutrinos

- EHEC ν's in reach!

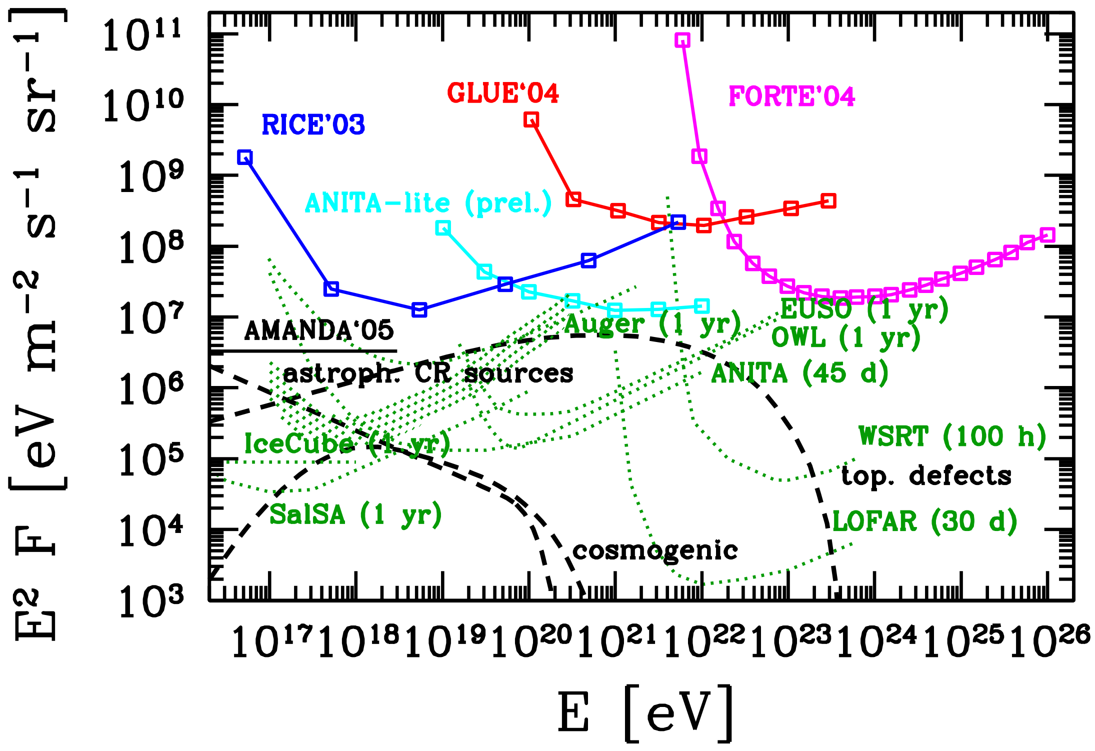
- Strong impact of measurement for
  - **particle physics**
  - **cosmology**



3. Fun with EHEC neutrinos

- EHEC ν's in reach!

- Strong impact of measurement for
  - **particle physics**
    - $*$ GUT parameters, e.g. m_X
  - **cosmology**



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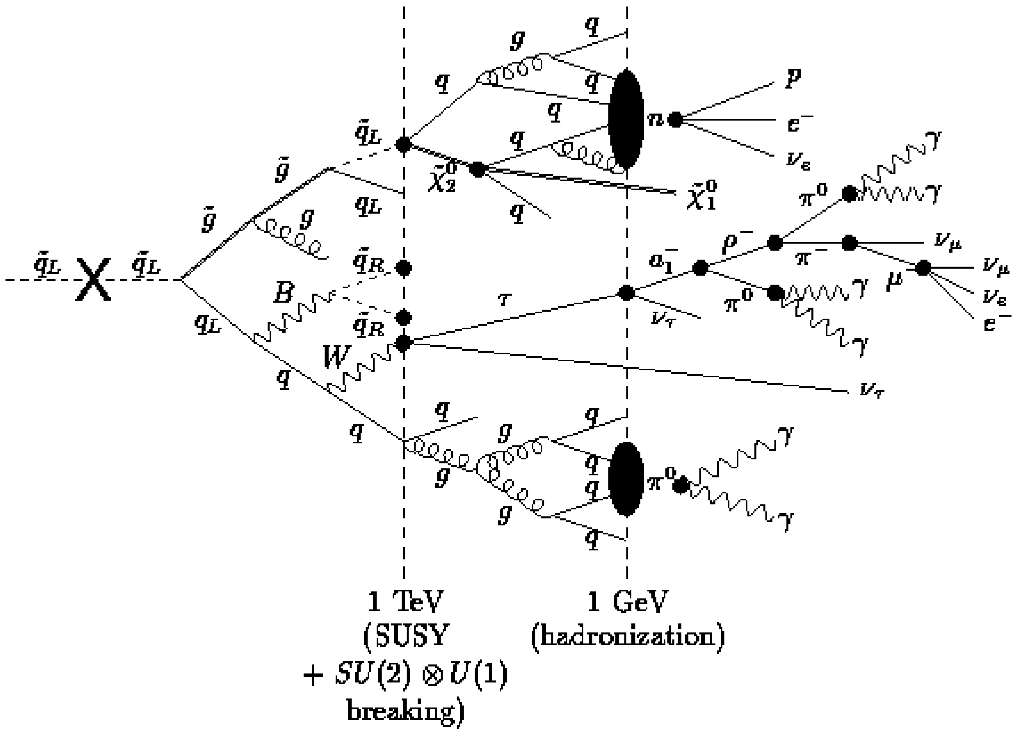

[Barbot,Drees '02]

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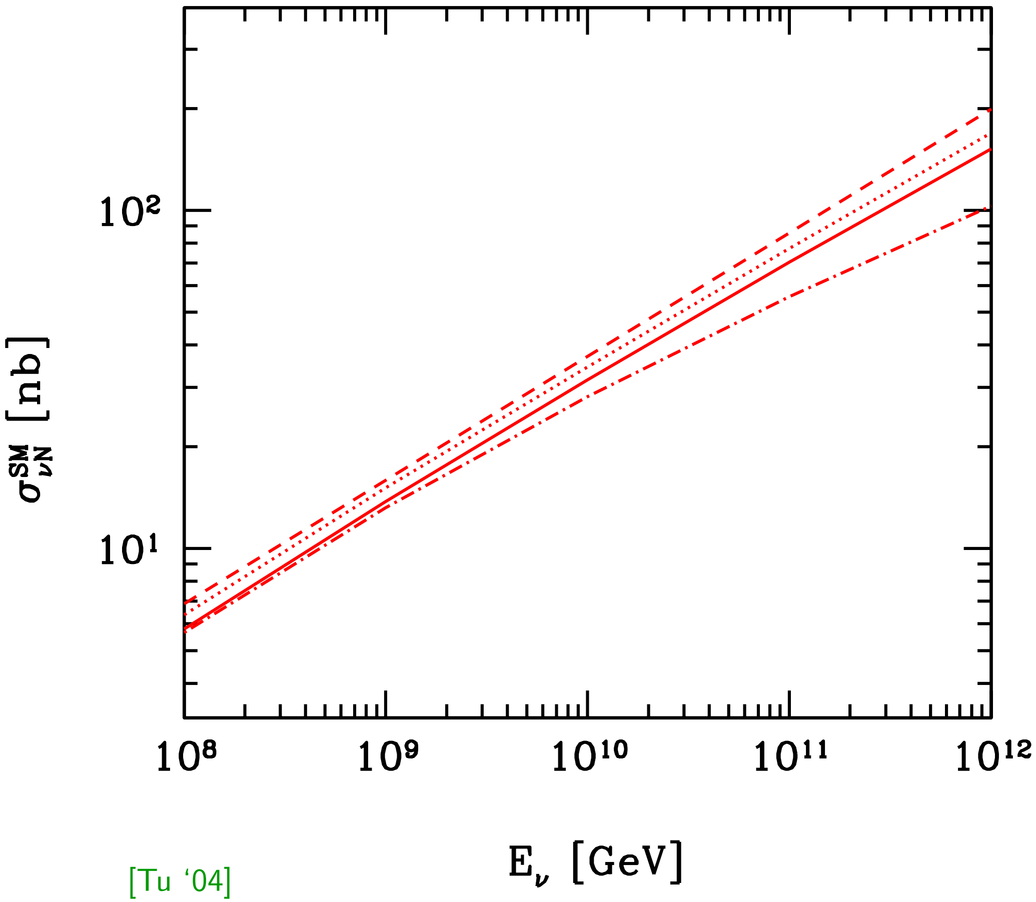

[Tu '04]

3. Fun with EHEC neutrinos

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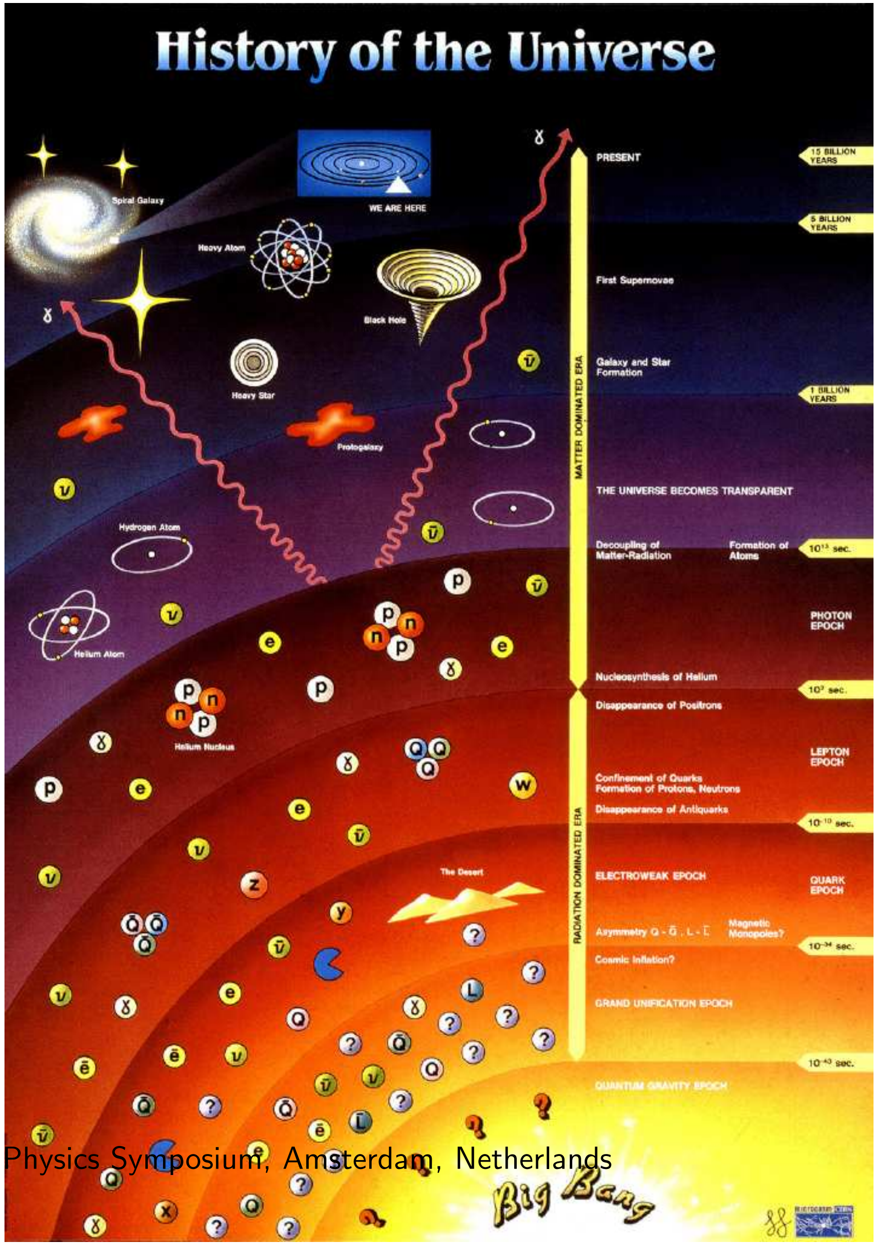
  – **cosmology**

    ∗ window on early phase transition
    ∗ Hubble expansion rate $H(z)$
    ∗ existence of the big bang relic neutrino background (CνB)

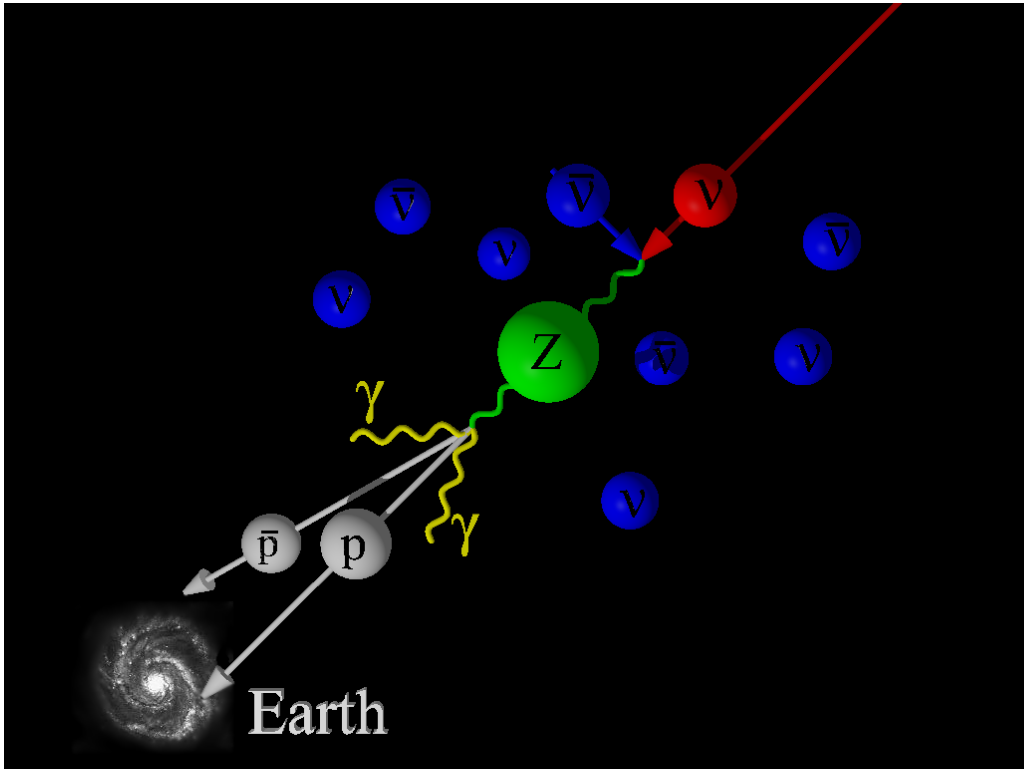


Absorption of EHEC neutrinos by the CνB

- At the resonance energies

$$E_\nu^{\rm res} = \frac{m_Z^2}{2m_\nu} \simeq 4 \times 10^{21}\ {\rm eV} \left(\frac{\rm eV}{m_\nu}\right)$$

EHEC neutrinos annihilate with relic neutrinos into Z bosons



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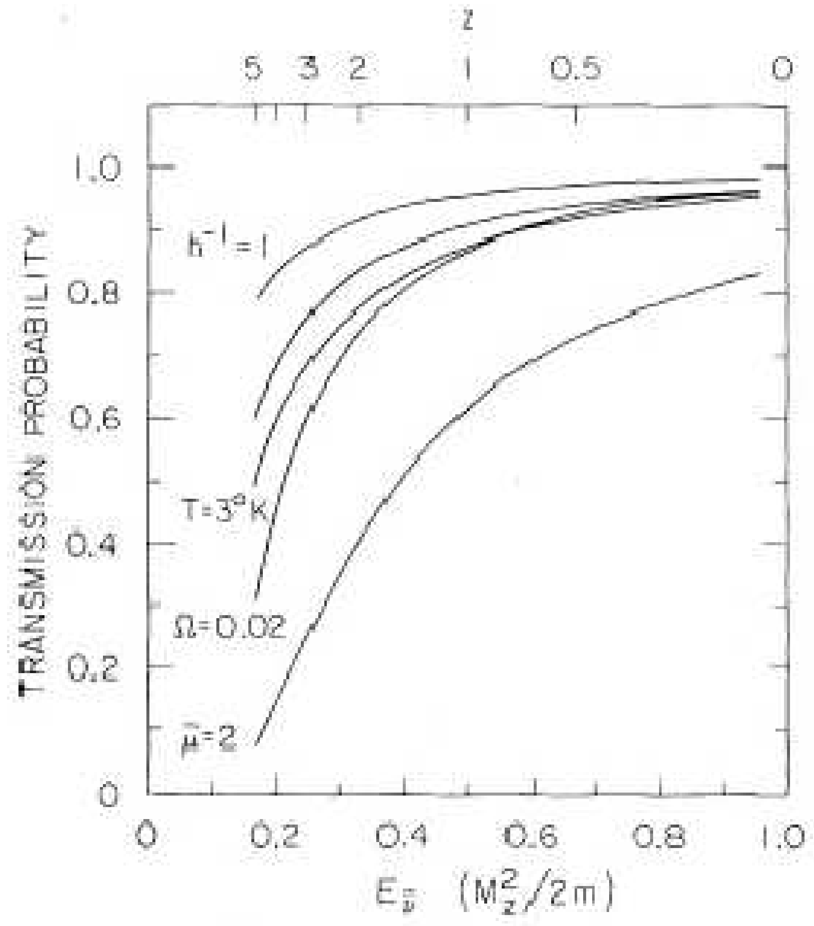

[Weiler '82]

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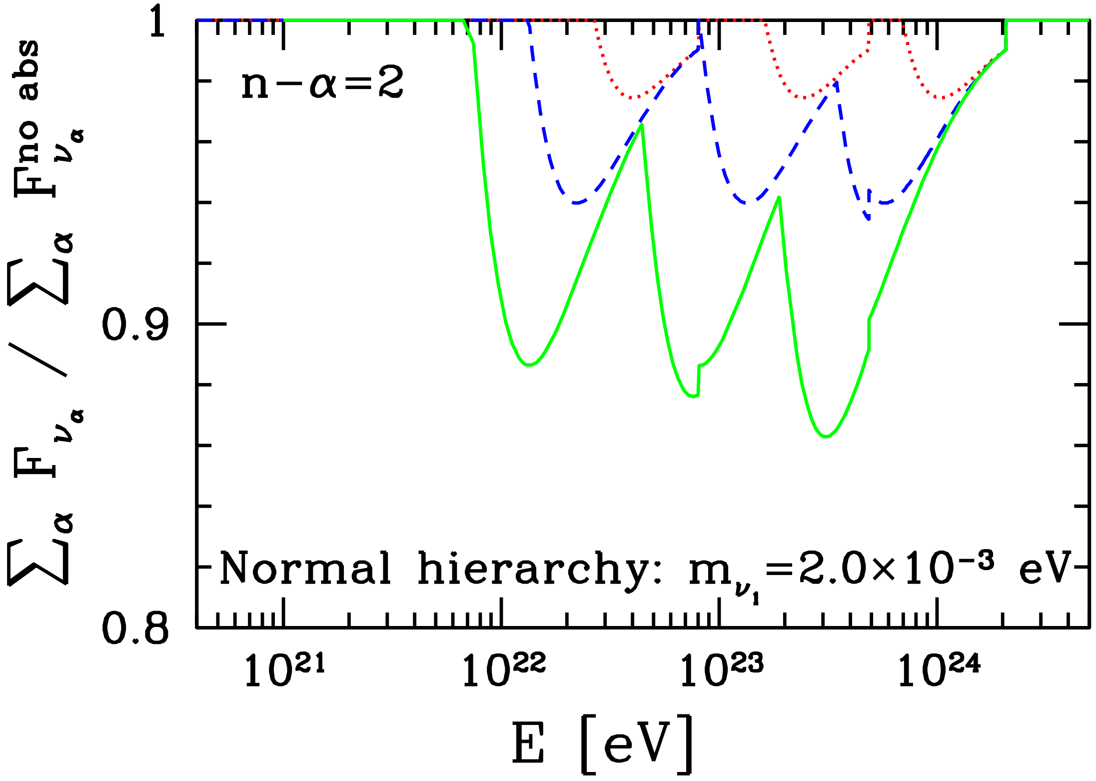

[Eberle,AR,Song,Weiler '04]

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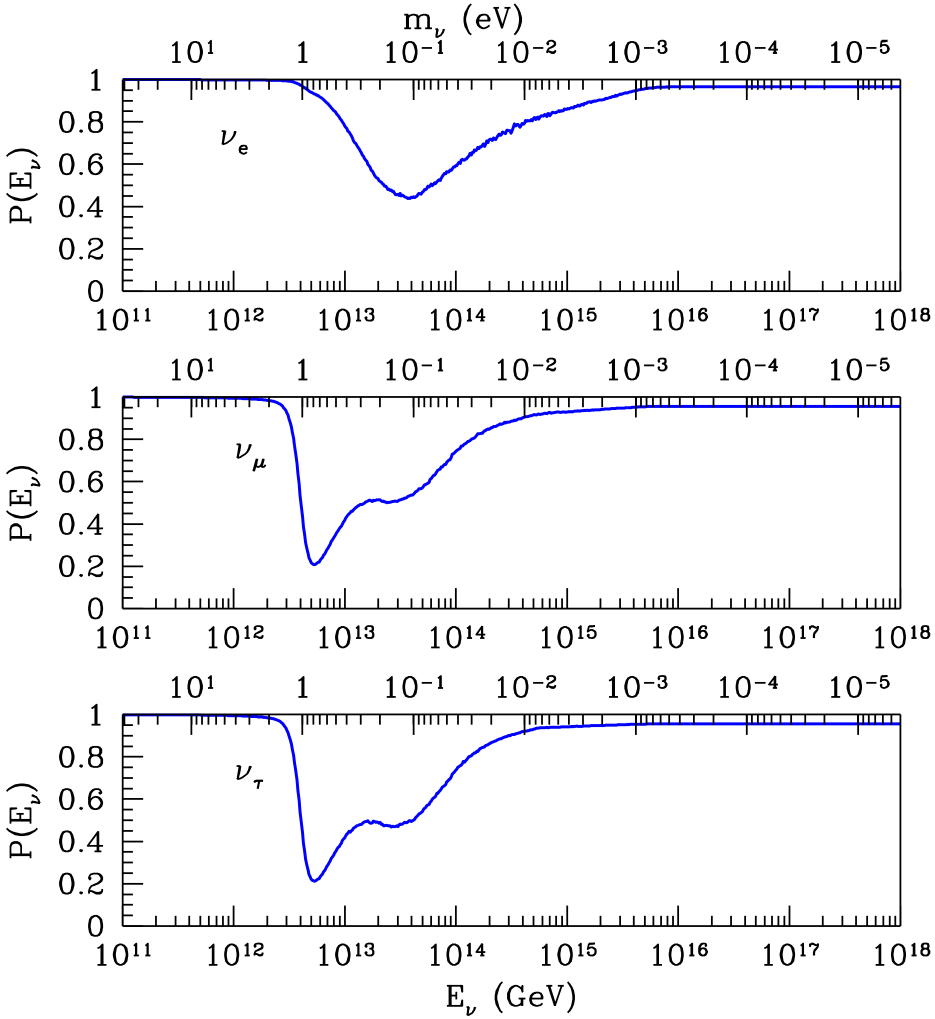

[Barenboim,Mena,Quigg '05]

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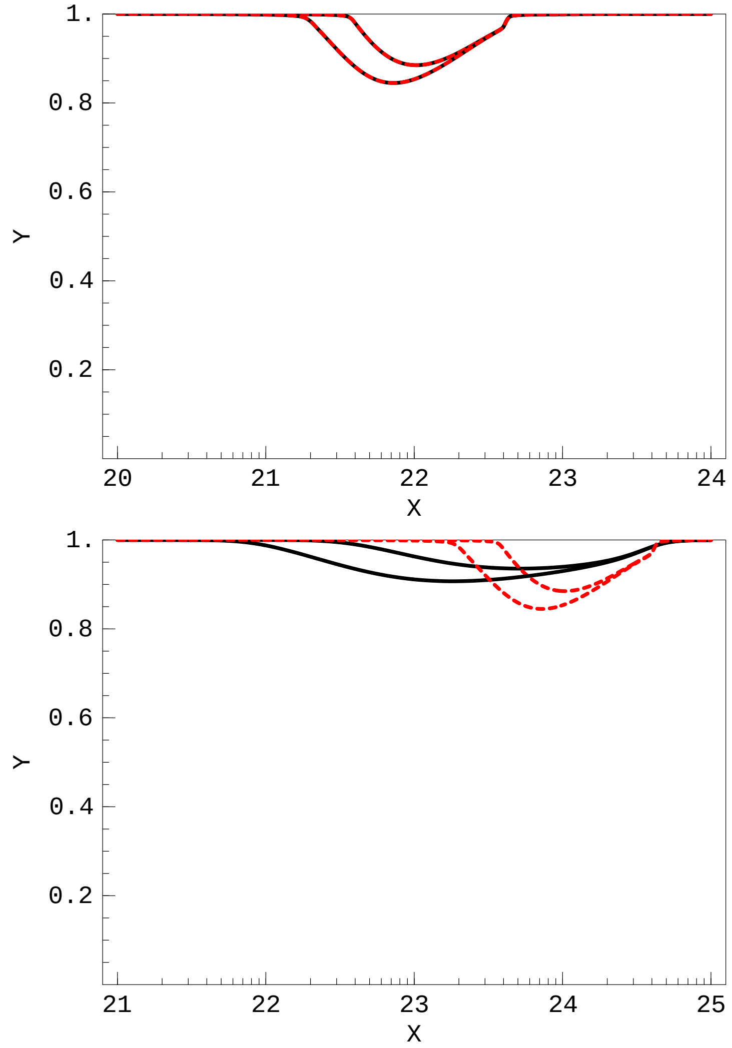

[D'Olivo,Nellen,Sahu,Van Elewyck '05]

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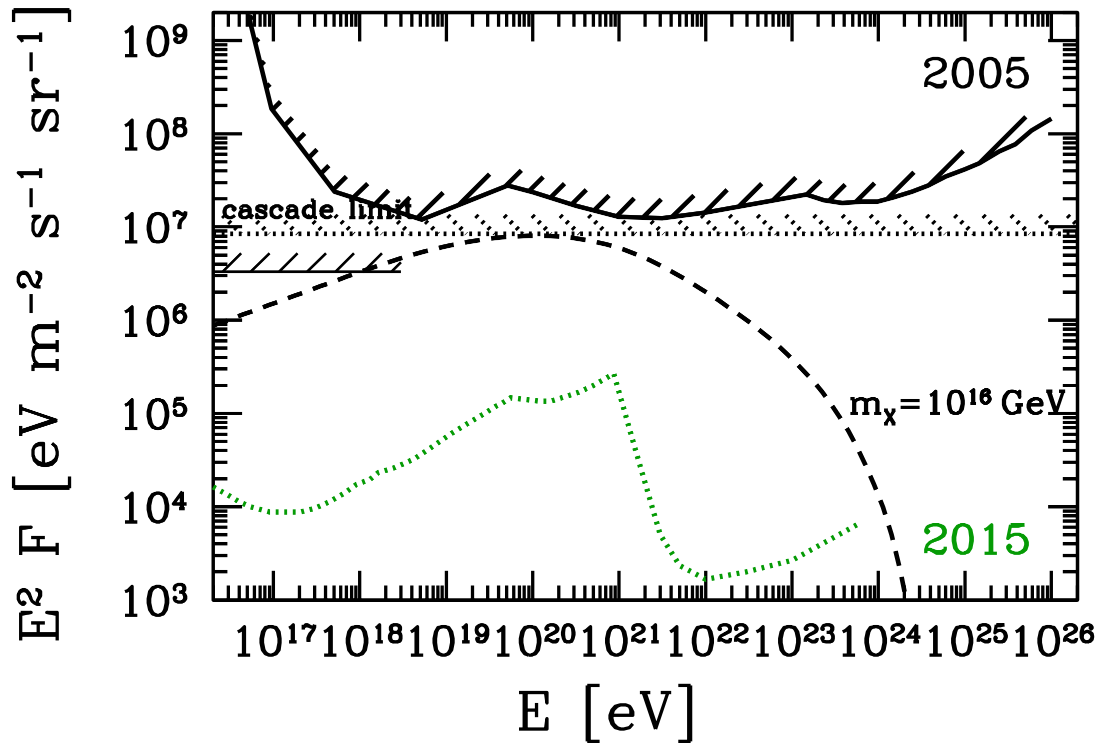
⇒ Absorption dips in EHEC neutrino spectra

- Detectable within next decade if
  - $m_X \gtrsim 10^{15}$ GeV
  - EHEC neutrino flux close to current observational bounds



[Fodor,Katz,AR,Weiler,Wong,in prep.]

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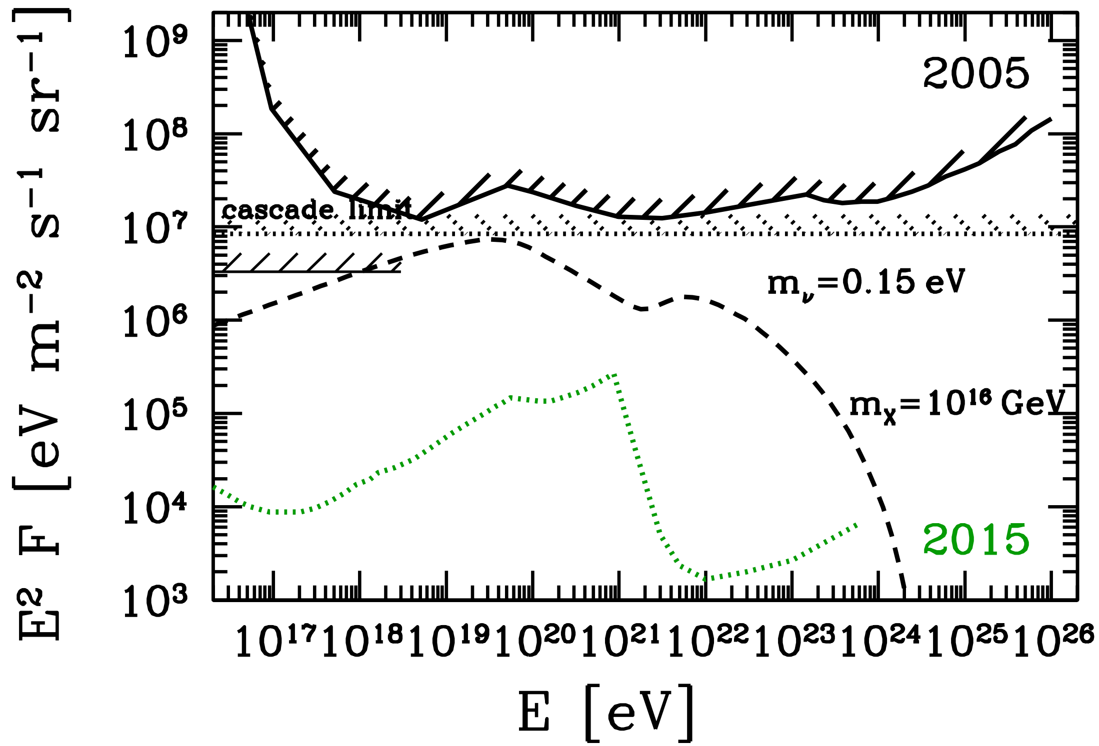

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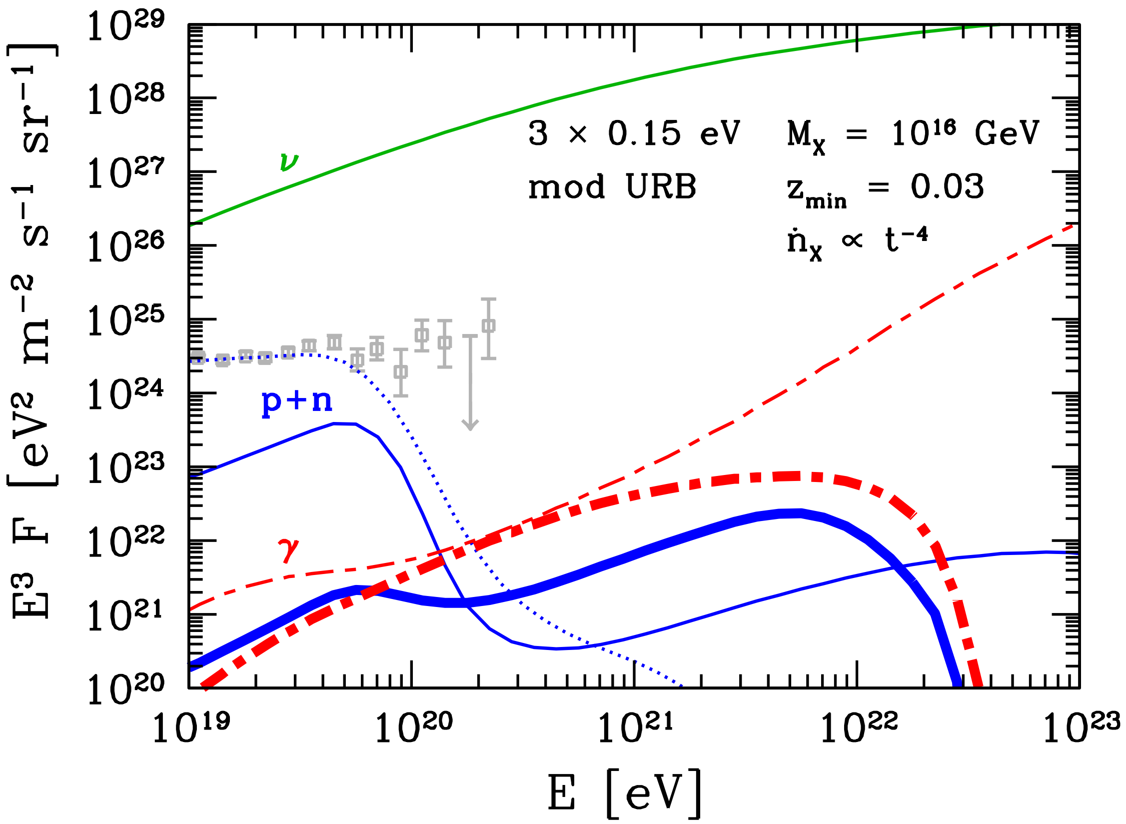
- Z-bursts as EHEC recovery



[Fodor,Katz,AR,Weiler,Wong,in prep.]

4. Conclusions

- Exciting times for EHEC neutrinos:
  - – many observatories under construction
  - ⇒ appreciable event samples

- Expect strong impact on
  - – astrophysics
  - – particle physics
  - – cosmology